ACHIEVEMENT THROUGH ELECTRONICS

CLASS C
RF POWER AMPLIFIERS

C205

NATIONAL RADIO INSTITUTE • WASHINGTON, D. C.

CLASS C RF POWER AMPLIFIERS

C205

STUDY SCHEDULE

☐ 1. **Introduction** . . . . Pages 1 - 3
Here you get a brief look at how power amplifiers are used and learn how to calculate their efficiency.

☐ 2. **RF Power Amplifier Fundamentals** . . . . Pages 4 - 12
This section discusses the basic class C amplifier.

☐ 3. **Vacuum Tube RF Power Amplifiers** . . . . Pages 13 - 27
Here you learn about practical class C amplifiers using vacuum tubes.

☐ 4. **Transistor Power Amplifiers** . . . . Pages 28 - 36
In this section, circuits which illustrate the important features of transistor rf amplifiers are discussed in detail.

☐ 5. **Adjusting Class C Amplifiers** . . . . Pages 37 - 41
Here a typical adjustment procedure for both a vacuum tube and a transistor class C stage is given.

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CLASS C RF POWER AMPLIFIERS

A radio transmitter is a device for converting some form of intelligence into electrical impulses suitable for transmission through space. In its simplest form, a transmitter consists of a source of rf energy, called the master oscillator, and one or more stages of rf power amplification.

In practical transmitters, such as the one shown in block diagram form in Fig. 1, there are a number of stages between the master oscillator and the antenna. Since each stage is a form of rf power amplifier, let's briefly discuss the particular role each one plays in the overall operation of the transmitter.

Immediately following the master oscillator is a stage called the buffer amplifier. Its purpose is to present a light constant load to the oscillator, which helps maintain a stable oscillator frequency. The FCC requires that very close control of output frequency be maintained on all radio transmitters under its jurisdiction.

The next stage, called a frequency multiplier, produces an output whose frequency is some multiple of the input frequency. The presence of this stage permits the master oscillator to be operated at a frequency lower than the transmitted frequency. It is much easier to design highly stable oscillator circuits at the lower radio frequencies; therefore, one or more frequency multiplier stages are an essential part of most radio transmitters.

The driver and power output stages provide the remaining amplification necessary to supply power to the antenna. This output power may range from less than 100 watts to 1 million watts, depending on the transmitter type and the purpose for which it is to be used. In recent years low power circuits, which formerly used vacuum tubes, have been

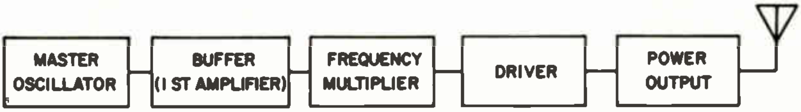


Fig. 1. Block diagram of a basic transmitter. All the stages are operated class C.

redesigned to use economical, efficient transistors. In many low to medium power mobile transmitters, transistors are used in all stages delivering as much as 75 watts of rf output power at 175 MHz. In other transmitters, all but the driver and final amplifier (power output) stages have been replaced by transistors. There is every reason to suppose that this trend will continue as the high-frequency power handling capability of transistors is improved.

The vacuum tube, however, is still used in high power stages of transmitters which are employed in the AM, TV and FM broadcast fields. It will no doubt remain so for quite some time to come. Very large vacuum tubes are required to handle the enormous power outputs of these transmitters. There are three characteristics of all rf power amplifiers, transistors or vacuum tubes which are of concern to us. They are linearity, power gain, and efficiency.

The linearity of an amplifier is a measure of how closely the amplified output follows the input; in other words, a measure of how much distortion is introduced into the output signal by the amplifier. Linear amplifiers, which introduce very little distortion into the signals they amplify, are a subject in themselves and will be considered in a later lesson.

The power gain of an amplifier, usually expressed in db, tells us how much the power level of the input signal is increased by the amplifier. Power gain depends on circuit design and the tube or transistor type used in the circuit. Beam power tetrodes have the highest power gain of any other conventional vacuum tube type. For this, as well as other reasons, the beam power tetrode is the most commonly used tube in modern transmitters. The power gain of transistors does not compare favorably with that of vacuum tubes at higher radio frequencies. This limitation may be partially overcome by adding more stages or using more than one transistor in each stage.

The efficiency of an amplifier, expressed as a percentage, is the amount of dc input power to the stage actually converted to rf energy at the output. In a vacuum tube stage, the power input is the product of the plate supply voltage times the average current. For example, suppose the plate supply voltage is 3000 volts, the plate current 450 milliamps, and the power output of the stage 1000 watts. The dc input power to the stage is:

$$P = E \times I$$

$$P = 3000 \times .45 = 1350 \text{ watts}$$

The efficiency of the stage can then be found by using the following formula:

$$\%\ \text{Efficiency} = \frac{\text{Power Out}}{\text{Power In}} \times 100$$

$$\%\ \text{Efficiency} = \frac{1000}{1350} \times 100 = 74\%$$

In a previous lesson, you learned that class C amplifiers give the highest practical efficiency, ranging up to 75%. This is compared to efficiencies of 35% to 50% for class B and as little as 30% to 35% for class A. However, the high efficiency of class C amplifiers is obtained at the expense of linearity. As you'll remember, output current flows for less than half the input cycle in a class C amplifier. This output current pulse bears little resemblance to the input signal which produced it and is therefore highly distorted.

If the output circuit of the class C amplifier is a resonant tank, this current pulse shock-excites the tank so that a complete sine wave is produced. Thus the nonlinearity of the class C amplifier is effectively eliminated when a single rf frequency (a sine wave) is to be amplified. This, along with the class C amplifier's high efficiency, makes it suitable to many rf power amplifier applications.

In the next section we'll discuss class C rf amplifier fundamentals. The information presented in this section applies to both vacuum tubes and transistors. Later, we'll discuss specific applications of vacuum tube and transistor amplifiers. In the final section, we'll talk about the various adjustments which may be made to both types of amplifier circuits.

RF Power Amplifier Fundamentals

In any amplifier, heat is generated by the current flow through the internal resistance of the stage. The power used to generate this heat represents wasted energy and subtracts from the power that could go to the output. The high efficiency of a class C amplifier is due largely to the fact that current flows for a relatively short portion of the input cycle. It is only during this short conducting period that power-wasting heat is generated within the amplifier. To begin our discussion of class C amplifiers, we'll consider the relationships between the current conducting time and the signal voltage waveforms in an operating class C amplifier.

CURRENT AND VOLTAGE RELATIONSHIPS

The graph in Fig. 2 shows the output current pulse produced by an input signal at various dc bias levels. Look first at the signal at bias level 1. This signal is below the cutoff value of the amplifier for all of the negative half-cycle and nearly all of the positive half-cycle. Output current flows only for the time the input voltage goes above cutoff. Now look at the signal at bias level 2. It has the same amplitude as the first signal but, because we've increased the bias, this signal exceeds the cutoff level for a shorter period. As a result, the output current pulse produced

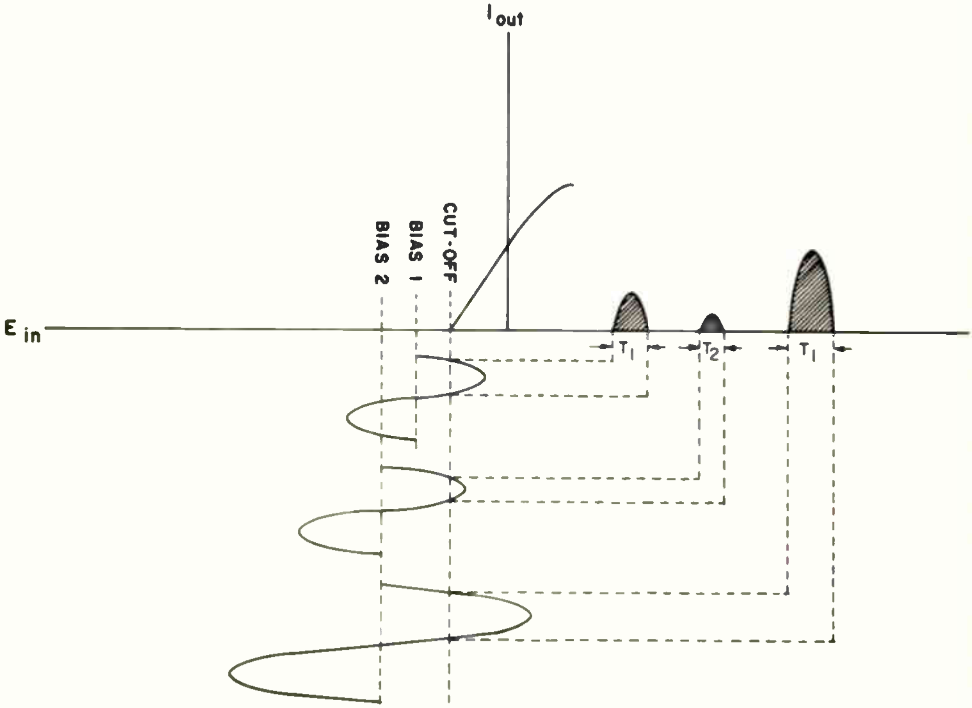


Fig. 2. Output current pulse produced by input signals at various amplitudes and bias levels.

also flows for a shorter period and is lower in amplitude. Increasing the amplitude of the input voltage has the same effect as decreasing the bias. That is, the output current flows for a longer time.

Another way of looking at these basic relationships is shown in Fig. 3. Fig. 3A shows two basic class C amplifiers; one uses a vacuum tube, the other a transistor. Fig. 3B shows the voltage and current waveforms appearing at the inputs and outputs of the amplifiers. Again notice that output current flows only during the period when the input signal exceeds the cutoff level of the amplifier. The output voltage waveform E_{out} is produced by the flywheel action of the resonant output circuit.

Conduction Angle. There are 360 electrical degrees in one complete cycle of a sine wave. The number of electrical degrees the output current flows in a class C amplifier is called the conduction angle or operating angle of the stage. As you've seen, the operating angle depends on both the dc bias and the amplitude of the driving signal. Although amplifier efficiency is higher at the smaller operating angles, the power output is less because the output current pulse is reduced in amplitude and flows for a shorter period. Therefore, the operating angle must be a compromise between maximum efficiency and the highest power output. In making this compromise, the driving signal is maintained at a level sufficient to drive the stage into saturation while the bias is adjusted for the correct operating angle.

Driving Power. To drive a vacuum tube amplifier into saturation requires that the grid be driven positive. The positive grid

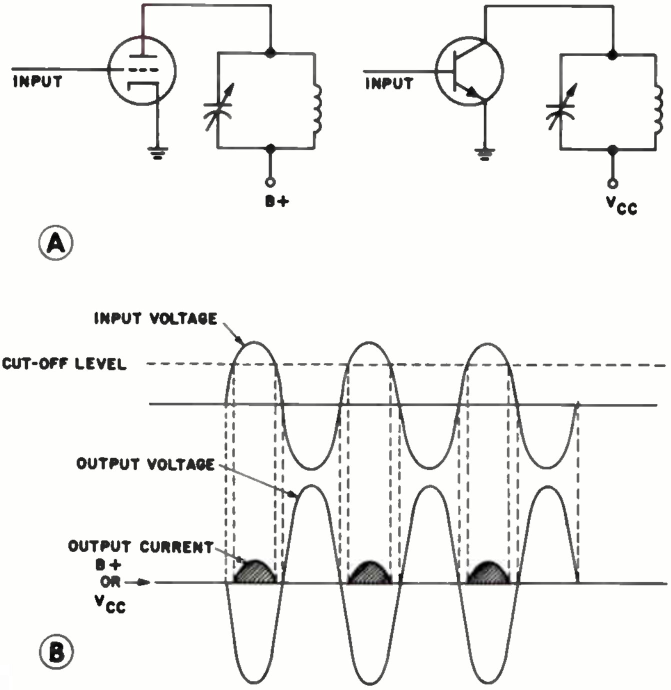


Fig. 3. Basic relationships between current and signal voltages in a class C amplifier.

draws current, causing power to be consumed in the grid circuit. Likewise, in a transistor amplifier, base current flows during the time the driving signal forward-biases the emitter-base junction. The result of this base current flow is that power is consumed in the base circuit.

The power consumed in the input circuit of a class C amplifier, called the driving power, must be supplied by the previous stage. Thus the input circuit of one class C amplifier represents the load on the stage which comes before it. Furthermore, this load presented by the input circuit varies over the period of an operating cycle, reaching a maximum when the input signal causes maximum current to be drawn. As we'll see later, we can use this current flow in the input circuit to develop bias for the stage.

TANK CIRCUITS

The resonant circuit in the output of a class C amplifier has several important jobs to do. We've already mentioned the most basic of these, that of changing the output current pulse into a complete sine wave. This resonant circuit is also required to present the proper load impedance to the stage, and to suppress the undesired harmonics generated within the stage. Let's discuss these last two in detail.

Load Impedance. In order to obtain the maximum power gain from a class C amplifier, or any other amplifier for that matter, the impedance of the load must match the internal impedance of the amplifier. However, do not confuse power gain with power output. It is quite possible that an amplifier operating with a matched load, for maximum power gain, is not delivering its maximum output power.

This is especially true for transistor rf power amplifiers. These amplifiers are very often designed to operate from automotive type battery supplies, thus limiting collector supply voltages to the 12 to 28 volt range. With the load matched to the internal impedance of the amplifier, there may be insufficient collector current flow to give the required power output. Using a value of load resistance lower than the input impedance of the stage results in a greater collector current flow and higher power output. Therefore, in some cases power gain must be sacrificed for power output.

Factors Affecting Impedance. Since the output tank circuit must offer the correct load impedance for the class C amplifier, let's look at some of the factors which affect this impedance. We know that to be resonant, the L and the C of the tank circuit must offer equal reactances at the operating frequency. If we increase the value of L, the value of X_L will increase. To maintain resonance, we must increase X_C by decreasing C. Having increased the value of X_L and X_C by equal amounts, we have increased the total impedance of the circuit without affecting the resonant frequency.

Any resistance present in the tank acts to decrease the total impedance of the circuit. The values of C, L, and R are related to total impedance by the following formula:

$$Z = \frac{L}{CR}$$

From the formula, you can see that increasing the ratio of L to C in the tank causes the impedance to increase. Increasing the resistance in the tank causes impedance to decrease. This leads us to a discussion of tank circuit Q.

Circuit Q. The Q of a coil, as you know, is the ratio of its reactance to its resistance or:

$$Q = \frac{X_L}{R}$$

A capacitor also has a Q, but its value is very large due to the capacitor's low internal resistance. The Q of a tank circuit, therefore, is equal to the Q of the coil.

Fig. 4 shows an amplifier with a parallel-tuned tank circuit in its output. At the operating frequency of this amplifier, let's assume the X_L of the coil is 6000 ohms and its resistance (R_S) is 20 ohms. The Q of this unloaded tank circuit then is:

$$Q = \frac{X_L}{R_S} = \frac{6000}{20} = 300$$

The Q of unloaded tank circuits in practical transmitters may range from 200 to 800. Fig. 5A shows the same amplifier of Fig. 4 inductively coupled to a load. This load might be a transmission line, an antenna, or another rf amplifier. The effect of this load is to reflect an additional resistance into the tank circuit. The equivalent circuit, shown in Fig. 5B, contains this reflected resistance ($R_L{}'$) in series with the resistance of the coil. The exact value of $R_L{}'$ depends on the value of the load resistance as well as the coupling to the load. We'll assume a value of 380 ohms for our discussion. The Q of the tank now becomes:

$$Q = \frac{X_L}{R_L{}' + R_S} = \frac{6000}{400} = 15$$

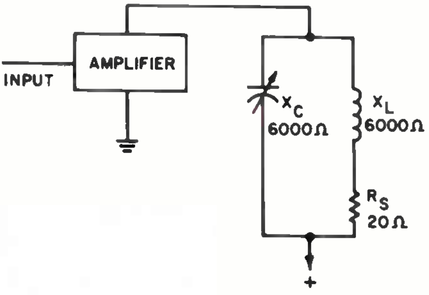


Fig. 4. Amplifier with a parallel tuned output tank showing impedances at resonance.

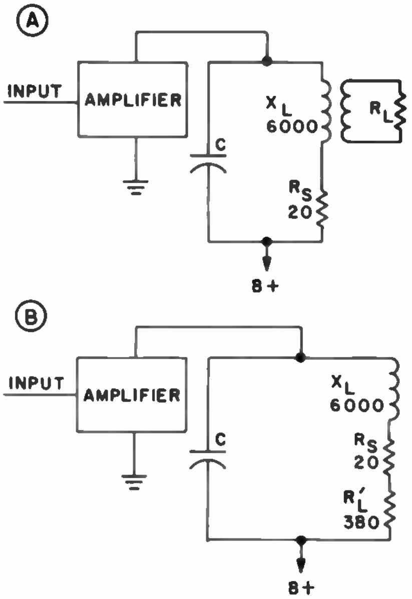


Fig. 5. Tank circuit coupled to a load and its equivalent circuit.

Thus, the Q of the tank circuit went from an unloaded value of 300 to the loaded value of 15 due to the resistance reflected into the tank circuit by the load. From the previous discussion of tank impedance, you know that this additional resistance in the tank also decreases the impedance of the tank. Tank Q and tank impedance are closely related quantities. Factors which change one will also change the other in the same direction.

Let's see now why this is important.

You know that only the resistance in a circuit consumes power. Inductive and capacitive reactances, under conditions of resonance, merely transfer energy back and forth between themselves. Therefore, when the tank is loaded, all of the power in the circuit is consumed by the resistances R_S and R_L'. The power consumed in R_L' represents power consumed by the load, while that consumed by R_S is dissipated as heat in the tank circuit. From Ohm's Law we derive that $P = I^2 R$, so the power consumed by the load far exceeds that lost as heat in the tank. This is because of a larger value of R_L'. We can actually calculate the efficiency of the tank circuit by the formula:

$$E_{ff} = \left(1 - \frac{Q_L}{Q_U}\right) \times 100$$

In our example, the unloaded Q (Q_U) was 300, and the loaded Q (Q_L) was 15. Therefore:

$$E_{ff} = \left(1 - \frac{15}{300}\right) \times 100$$

$$E_{ff} = (1 - .05) \times 100 = 95\%$$

Suppose we increased the coupling to the load and reflected a larger value of resistance into the tank. This would decrease Q_L without affecting Q_U, resulting in a higher tank circuit efficiency. But remember, tank impedance is dependent on the resistance in the tank, so changing the coupling to the load changes the tank impedance. Since the stage is designed for best operation at a particular tank impedance, there is only one correct value of loading on the tank.

Reducing Harmonics. The output pulse of a class C amplifier contains, in addition to the fundamental, numerous harmonic frequency components. As you'll learn later in this lesson, this fact enables us to operate a class C stage as a frequency multiplier. The output tank circuit offers maximum impedance at the frequency to which it is tuned. Harmonic frequencies, seeing a relatively lower impedance, are not developed across the tank circuit in any great magnitude. The circuit which couples the tank to its load is usually designed with harmonic suppression in mind. Sometimes, special traps must be used in output coupling networks which either shunt the harmonics to ground or block their passage to the antenna.

An additional precaution against harmonic radiation is to use an electrostatic shield between two inductively coupled circuits. A shield of this type, called a Faraday screen, is shown in Fig. 6.

The Faraday screen consists of a number of wires fastened together at one end and open at the other. The ends of the wires that are connected together are grounded. Capacitively coupled harmonic currents will flow to the screen wires rather than to the pickup coil. At the

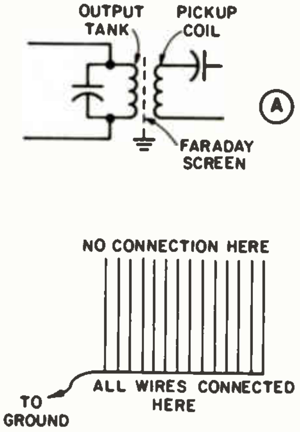


Fig. 6. An electrostatic shield or Faraday screen between the output tank and the antenna pick-up coil is used to prevent harmonic currents from flowing through the capacity between the coils.

same time, because the wires do not form closed circuits, there can be no voltage induced in them by the magnetic field. Therefore, they do not interfere with the inductive coupling between the output tank and the link coil. This method is very effective in reducing the transmission of harmonics from an output tank circuit to an antenna or transmission line.

COUPLING METHODS

The resonant tank in the output of a class C amplifier forms the basis of the coupling circuit to the amplifier's load. We know that the impedance presented to the stage by the output tank circuit depends, to a large measure, on the equivalent resistance in the tank. We also know that the value of this equivalent resistance is primarily that reflected into the tank by the load. To obtain the correct tank impedance for the amplifier, the coupling must reflect a certain value of resistance into the tank. In most cases, the actual value of the load resistance connected directly across the tank would not reflect the correct resistance into the tank. Therefore, the coupling method must give an impedance transformation. The simplest way to accomplish this impedance transformation is to use a transformer as a method of inductive coupling.

Inductive Coupling. Fig. 7 shows two amplifier stages inductively coupled together. In this circuit, the resistance reflected into the output tank for amplifier 1 is adjusted by varying the spacing between the coils. Varying this spacing also adjusts the drive to amplifier 2. The circuit is designed to reflect the correct resistance and provide the proper drive at the same setting.

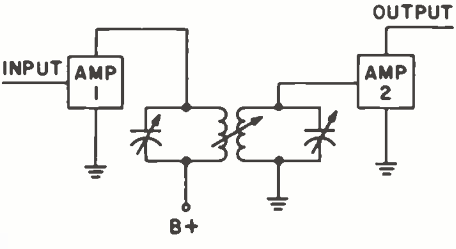


Fig. 7. Inductive coupled amplifiers.

A variation of inductive coupling is shown in Fig. 8. This method is called link coupling. It consists of a coil with only a few turns of wire inductively coupled to an output tank. A similar coil is inductively coupled to the load. The connection between the two coils is usually by means of shielded coaxial cable, so it may run some distance with very little loss. Link coupling may also be used between the final power amplifier in a transmitter and a low impedance transmission line. As in the conventional inductive coupling already discussed, the coupling is adjusted by varying the spacing between one of the link coils and the tank. Sometimes the link itself is tuned by a variable reactance. When this is done, the tuned link provides additional suppression of harmonics generated in the previous stages.

Notice that the method of applying B+ to the stage in Fig. 8 differs from that of Fig. 7. In Fig. 8, this voltage is applied through a radio frequency choke (rfc). The rfc offers a very high impedance at the operating frequency, so it keeps the signal voltage out of the power supply. When the power supply, the tank circuit, and the stage are connected in series, as in Fig. 7, the amplifier is said to be series-fed. When the power supply, tank circuit, and stage are in parallel (or shunt), as in Fig. 8, the amplifier is said to be shunt-fed.

Tapped Tank Circuits. Another

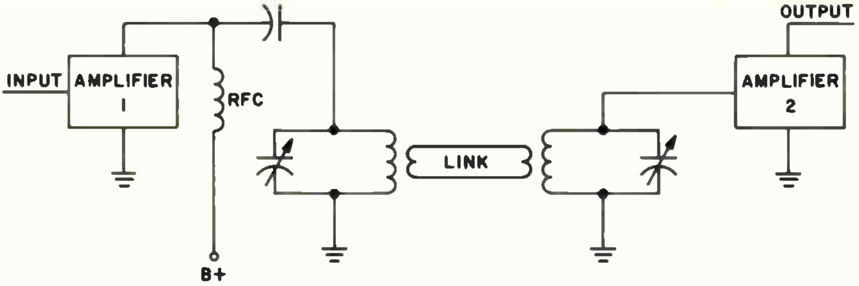


Fig. 8. Link coupled amplifiers.

method of obtaining an impedance transformation is to connect the load across only a portion of the tank coil. Such a method is shown in Fig. 9A. The value of resistance reflected into the tank is dependent on the position of the tap. In Fig. 9B, the tank capacitor is split to provide the impedance transformation. The values of C_1 and C_2 determine the value of load resistance seen by the tank (reflected resistance).

The methods shown in Figs. 9A and 9B may be combined as shown in Fig. 9C. With this circuit arrangement, the internal impedance of the stage, as seen by the tank, is transformed to a higher value by the tapped coil. Using this method the required value of loaded Q in the tank may be maintained in spite of low values of internal impedance (such as found in transistor stages). The values of C_1 and C_2, as before, determine the value of load resistance seen by the tank.

Network Coupling. Fig. 10 shows three types of networks frequently used to couple class C amplifiers to their loads. The various arms of each are shown as impedances in the figure. In practical networks of this type these impedances will be combinations of L and C components. Later on in your course you'll learn to calculate the reactance values for the arms of these networks to give a required impedance transformation. For now, it is enough for you to know

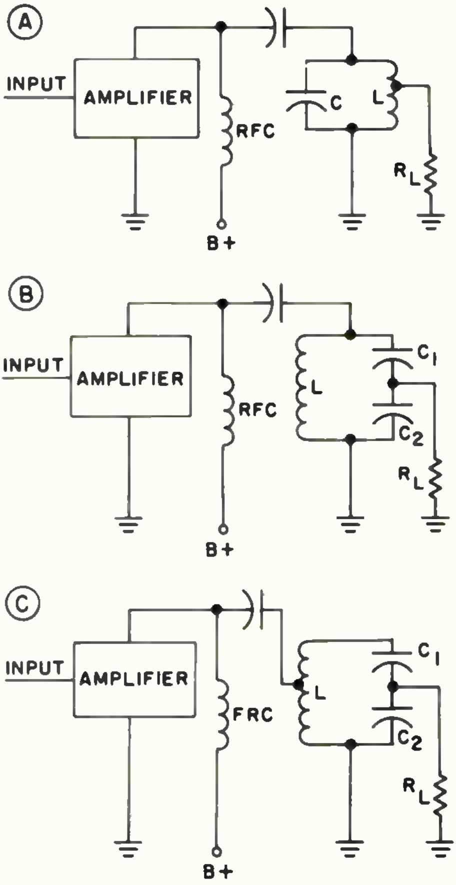


Fig. 9. Tapped tank circuits used for impedance transformation.

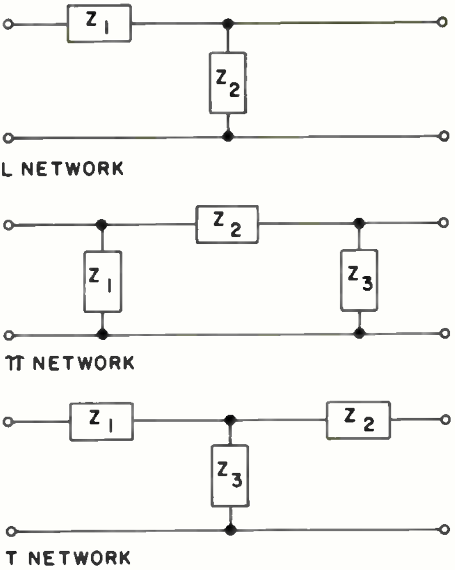


Fig. 10. Networks used to couple an amplifier to its load.

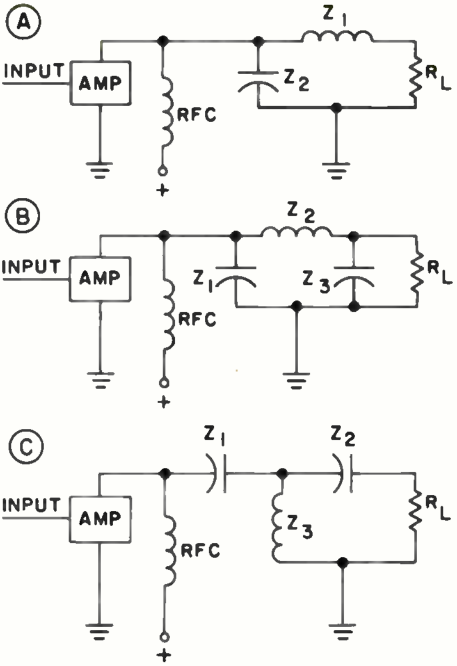


Fig. 11. Amplifiers using L, π, and T network coupling to load.

that they fulfill all the requirements of a tank circuit and can provide impedance transformations over a very wide range of values. In addition, these circuits can be easily designed to attenuate undesired harmonic frequencies.

Fig. 11 shows an example of how each of these networks (L, π, T) is used to couple an amplifier to its load. The network used in any particular application depends on the magnitude of the impedance levels to be transformed. The networks themselves may be coupled together in a variety of combinations to provide the proper load to the amplifier and greater harmonic attenuation. It is important to remember in the examples of this section that R_L may represent the input of another amplifier, a transmission line, or an antenna. The only difference between these three types of loads, as far as the amplifier is concerned, is the impedance level. An antenna or transmission line usually offers a lower impedance, and therefore a greater load, to an amplifier than the input circuit of another amplifier.

SELF-TEST QUESTIONS

(a) What is the primary reason class C amplifiers operate at higher efficiencies than class A or class B amplifiers?

(b) What two factors affect the operating angle of a class C amplifier?

(c) Is impedance matching between an amplifier and its load always desirable? Why?

(d) Suppose we wanted to increase the impedance of a parallel-tuned tank without changing the coupling or the resonant frequency. What components in the tank should be changed and in what direction?

(e) If the coupling to a tank is adjusted to increase the load on the tank, what would happen to the loaded Q? The unloaded Q? The efficiency of the tank?

(f) If the loaded Q of a tank decreases, what would happen to the tank impedance?

(g) How does the output tank circuit reduce the harmonics present in the output of a class C amplifier?

(h) How would you increase the coupling between two inductively coupled amplifiers?

(i) Is amplifier I (shown in Fig. 6) series-fed or shunt-fed?

(j) In a transistor rf power amplifier, the internal resistance of the stage is found to load the output tank so heavily that a high enough loaded Q cannot be obtained. If the amplifier is connected to the tank as shown in Fig. 6, what change could be made in the circuit to increase the loaded Q of the tank?

(k) Normally, which would more heavily load a class C amplifier: an antenna or another class C amplifier?

Vacuum Tube RF Power Amplifiers

Now that you have a basic understanding of rf power amplifiers, let's take a detailed look at some applications which use vacuum tubes. In the first section we'll discuss methods of obtaining the class C bias necessary to get the proper conduction angle from the amplifier. Then we'll look at some of the methods employed to insure stable amplifier operation. Finally, we'll take a look at some practical rf amplifier circuits, including frequency multipliers.

BIAS METHODS

Some typical class C bias methods are shown in Fig. 12. The three most common biasing methods are shown at A, B, and C.

External Bias. In Fig. 12A, the bias is obtained from an external bias supply and is coupled through an isolating rf choke to the grid of the stage. The rf choke acts as a high impedance and prevents the power supply circuit from acting as a shunt for the radio-frequency energy.

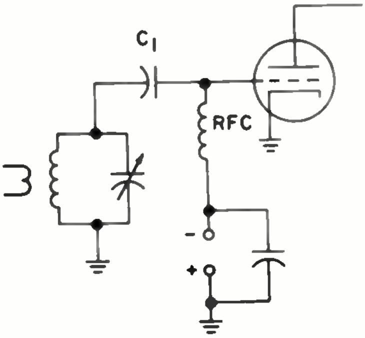


Fig. 12A. External bias.

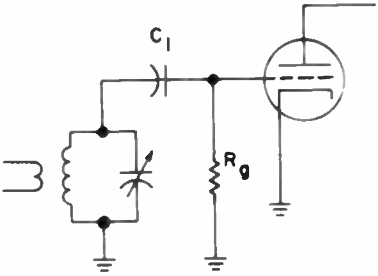


Fig. 12B. Grid-leak bias.

Grid-Leak Bias. In Fig. 12B, grid-leak bias is used. With this method of biasing, the grid current that flows during the crest of the positive half of the cycle of the incoming signal charges capacitor C_1 to a high negative value. During the interval between grid current pulses, the capacitor discharges through grid-leak resistor R_g. The discharge current develops a steady negative voltage across R_g. The value of this voltage depends upon the value of R_g and on the current through it. One advantage of this circuit is that the bias adjusts itself when the driving power is changed. Increasing the driving power increases the grid current and therefore increases the voltage drop across R_g. Thus, with grid-leak bias, changing the driving power does not appreciably change the operating angle.

A disadvantage of using grid-leak bias alone is that if there is a failure in the preceding stage, so that no excitation is supplied to the grid of the amplifier, there will be no bias developed. Excessive plate current will then flow, and if the circuit is not suitably protected, the tube and its associated components will be damaged.

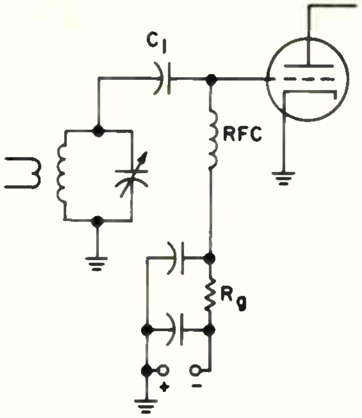


Fig. 12C. Combination external and grid-leak bias.

Combination External and Grid-Leak Bias. To protect the tube against loss of bias, a combination of external and grid-leak bias, shown in Fig. 12C, is often used. This circuit has the self-adjusting features of the circuit in Fig. 12B, and at the same time provides enough bias to protect the tube if there is a failure in the preceding stage.

Cathode Bias. The tube can also be protected against the loss of excitation by using the cathode bias combination, shown in Fig. 12D. The amount of protective bias, in either Fig. 12C or Fig. 12D, is chosen so that the plate current through the tube multiplied by the plate voltage is equal to or less than the maximum safe plate dissipation of the tube. The disadvantage of cathode bias is that part of the power supplied to the plate circuit of the tube is wasted in the cathode resistor. In large high-power stages this might be a substanial amount.

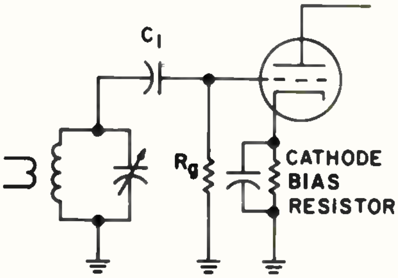


Fig. 12D. Cathode bias.

Variations. The circuits in Figs. 12A through 12D show the basic class C bias methods. There are also some minor variations of these circuits.

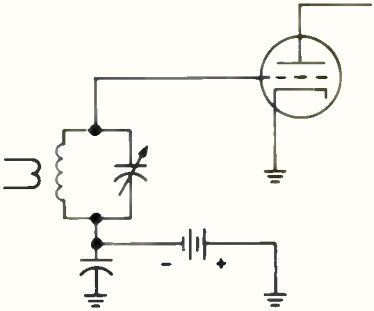


Fig. 12E. Variation of circuit shown in Fig. 12A.

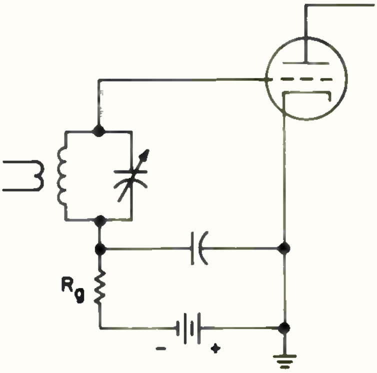


Fig. 12F. Variation of circuit shown in Fig. 12C.

For example, the circuit shown in Fig. 12A may be rearranged as in Fig. 12E, eliminating the rf choke and coupling capacitor. The circuit in Fig. 12C may be rearranged as in Fig. 12F. Perhaps we should remind you that you will find minor variations in many circuits.

Do not conclude that a circuit is necessarily different from the basic circuit you have studied just because it has been changed slightly. Study the circuit carefully and you will probably find that the method of operation is basically the same.

AMPLIFIER STABILITY

Class C amplifiers using triode tubes will go into self-oscillation easily because of feedback between the input and output circuits. As you will learn in a later lesson, a tuned-grid, tuned-plate oscillator is simply an unstable class C amplifier.

The feedback path in a triode is through the grid-to-plate capacity. Since this capacity is quite large in a triode tube, enough energy from the plate circuit can be fed back to the grid to overcome the grid-circuit losses and cause the stage to oscillate at a frequency near the resonant frequency of the tuned circuits.

Oscillation will not take place if the plate tank circuit is tuned precisely to resonance; the tank circuit must be slightly detuned to sustain oscillation. Precise adjustment, however, is very difficult. Even if you were able to make such an adjustment, the amplifier would be unstable. Slight changes in supply voltages and load would cause it to go into oscillation.

The feedback signal in a triode amplifier must be neutralized to prevent oscillation. The stage is neutralized by feeding a second signal back into the grid circuit. This second signal must be of opposite polarity and of the same amplitude as the signal fed into the grid circuit through the grid-plate capacity of the tube in order to cancel the feedback.

The most basic method of neutralization is shown in Fig. 13. In this circuit, a coil is inserted between the grid and the plate. In series with the coil is a blocking capacitor, which keeps the dc plate voltage off the grid of the tube. It has no other effect on the neutralizing circuit. The value of the coil is chosen to resonate with the grid-to-plate capacity at the frequency to which the amplifier is tuned.

The current through the coil lags the voltage 90°; the current through the capacity leads the voltage 90°. Therefore, the currents through the coil and the capacity are 180° out-of-phase and cancel each other. The disadvantage of this simple and basic method of neutralization is that it must be retuned when the operating frequency is changed. Let's look at other methods of neutralization.

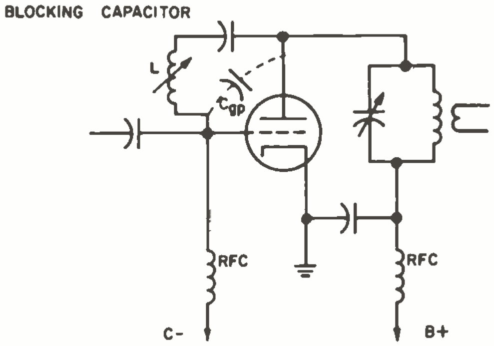


Fig. 13. Neutralization for a triode tube stage.

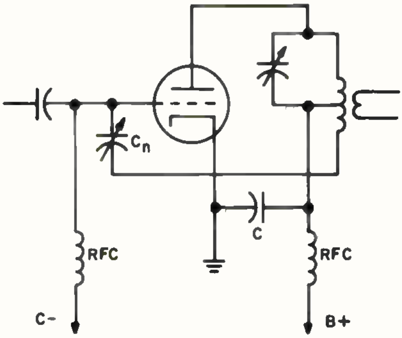


Fig. 14. Plate or "Hazeltine" neutralization.

Plate Neutralization. Fig. 14 shows a plate or "Hazeltine" neutralization. In this circuit arrangement, the coil used in the plate tank circuit is tapped, and the tap on the coil is operated at rf ground potential by grounding it through the capacitor C.

A signal voltage is developed between ground and the bottom end of the coil that is out-of-phase with the voltage at the plate end of the coil. By connecting the bottom of the tank circuit to the grid of the amplifier through the capacitor C_n, which is called the neutralizing capacitor, we can get a signal at the grid that will cancel the feedback from plate to grid through the tube capacity. Capacitor C_n is adjustable so that we can apply the exact amount of signal needed to cancel out the signal fed back through the tube.

The plate neutralization system can be considered as a balanced bridge circuit. A bridge circuit is shown in Fig. 15A. The input voltage is applied between terminals A and B and the output voltage is taken off between C and D. If the ratio of impedance Z_1 to impedance Z_2 is equal to the ratio of Z_3 to Z_4, the voltage between terminals C and D will be zero, and we say the bridge is balanced.

The plate neutralization system in Fig. 14 can be redrawn as a bridge circuit as shown in Fig. 15B. The voltage is applied to terminal A from the plate of the tube. The voltage applied to terminal B is the voltage induced in the lower half of the coil in the plate circuit of the tube. We have labeled this half of the coil L_2, and the upper half L_1. Terminal C of the bridge is connected to the grid of the tube and terminal D is grounded. L_1 is made equal to L_2 by center-tapping the coil. When C_n is adjusted to equal C_{gp}, the ratio of L_1 to L_2 will be equal to the ratio of C_{gp} to C_n. Then the bridge will be balanced, so there will be no voltage fed back to the grid circuit from the output circuit.

With this type of circuit, once the stage is neutralized it will remain neutralized over a reasonably wide frequency range, if the coil is exactly center-tapped, so that L_1 is exactly equal to L_2. If L_1 is not exactly equal to L_2, the stage can still be neutralized simply by making the ratio

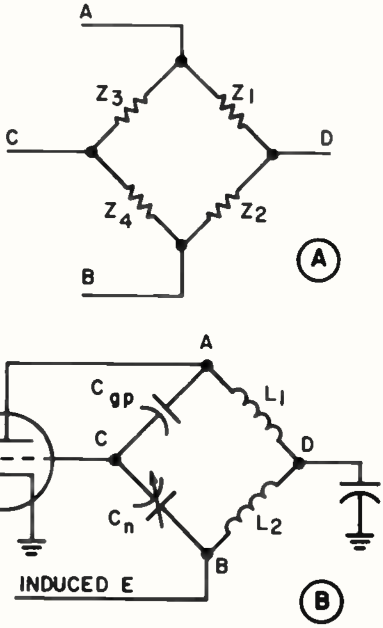


Fig. 15. Equivalent bridge arrangement of plate neutralization circuit.

of the impedance of C_{gp} to the impedance of C_n equal to the ratio of the impedance of L_1 to the impedance of L_2. If there is an appreciable difference between the values of L_1 and L_2, the frequency range over which the stage will remain neutralized becomes limited.

Another circuit for plate neutralization is shown in Fig. 16. In this circuit the center tap on the coil is not operated at rf ground potential; it is connected to B+ through an rf choke. The ground point is taken at the rotors of a split-stator tuning capacitor. A split-stator capacitor is a variable capacitor with one set of rotor plates and two sets of stator plates that are insulated from each other. The voltages at the two ends of the coil are equal and of opposite phase. The circuit in Fig. 16 can be shown as a balanced bridge by substituting the sections of the split-stator tuning capacitor for coils L_1 and L_2 in Fig. 15B. The rf ground in both circuits is made through a capacitor (marked C in Fig. 16).

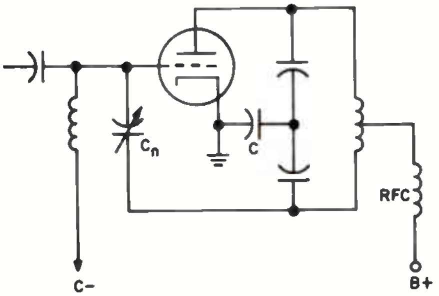


Fig. 16. Another plate neutralization circuit.

Grid Neutralization. The tapped-grid circuit arrangement shown in Fig. 17 can also be used for neutralization. This is referred to as grid neutralization or Rice neutralization. The neutralizing signal is taken from the plate and applied to one end of a tapped coil in the grid-tuned circuit. The rf ground connection is made to the center tap on the grid coil. The polarity of the feedback signal, introduced through the neutralizing capacitor C_n to one end of the grid coil, is in phase with the signal that is fed directly to the other end of the grid coil through the plate-grid capacity.

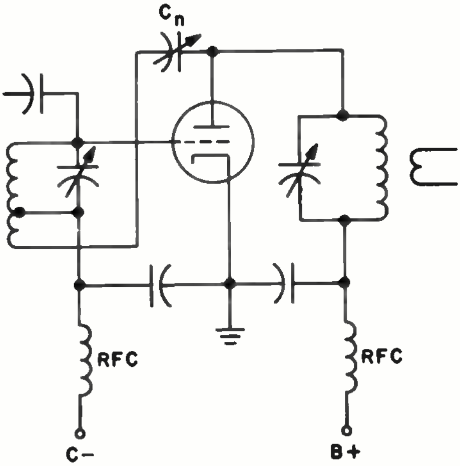


Fig. 17. Grid or "Rice" neutralization.

By properly adjusting the neutralizing capacitor C_n, voltage fed through it can be made equal to the voltage fed through the tube capacity. These two voltages will cause equal currents to flow through the

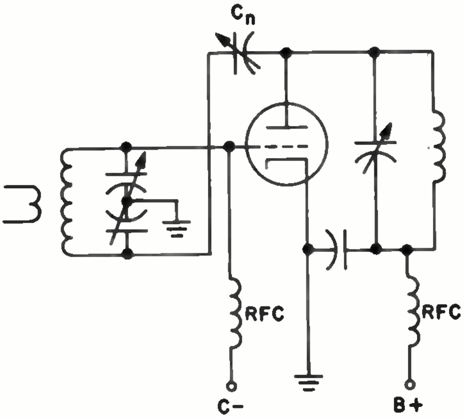


Fig. 18. Split-stator grid neutralization.

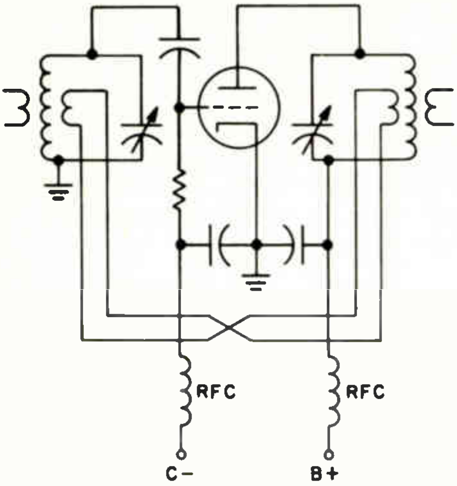


Fig. 19. Inductive neutralization.

grid coil in opposite directions. These currents will induce new voltages in the grid coil which will tend to cancel the voltage fed through C_n and C_{gp}. A split-stator version of grid neutralization is shown in Fig. 18. Its operation is essentially the same as that of Fig. 16.

Inductive Neutralization. Still another method of neutralization is shown in Fig. 19. This is referred to as inductive neutralization, because the neutralizing signal is obtained by inductive coupling between the plate and grid-tuned circuits. The signal induced in the grid circuit by the inductive link is opposite in polarity to the feedback signal, and gives feedback cancellation.

Parasitics. Neutralization of an amplifier is used to prevent oscillation at the frequency to which the grid and plate circuits are tuned, in other words, at the signal frequency. Some amplifiers go into oscillation at frequencies far removed from the desired signal frequency. Oscillations of this type are called "parasitic oscillations" or "parasitics."

The neutralization circuits we have just studied can do nothing to prevent this type of oscillation. Long leads, tube interelectrode capacities, rf chokes, and bypass capacitors are the major inductive and capacitive elements that cause parasitic oscillations.

Parasitics may exist at low or high frequencies, or at both low and high frequencies at once. They cause low operating efficiency and instability in the stage, erratic meter readings, radiation of improper carriers and sidebands, distortion, overheating of the amplifier tube, and premature breakdowns in the circuit parts. If grid-leak bias is used in the stage, parasitics will also cause changes in the grid bias.

Fig. 20A shows a typical class C amplifier stage. At the operating frequency, the grid and plate circuits are tuned by the coil and capacitor combinations L_1-C_1, and L_2-C_4. The stage is prevented from oscillating at the operating frequency by the signal fed back through neutralizing capacitor C_n.

Fig. 20B shows what the effective circuit would be if this stage were producing low-frequency parasitic oscillations. The grid circuit is now tuned by the parallel combination of the grid choke, RFC_1, and the grid bypass capacitor, C_2. Since these oscillations usually take place at frequencies below 200 kilohertz, coil L_1 has very little reactance and serves merely as a connecting lead from the grid to the junction of C_2 and RFC_1. This places the rf choke and grid bypass capacitor in parallel between grid and ground.

The tuned circuit in the plate at the low frequencies is the plate bypass C_3 and the plate rf choke. Here, too, the regular tank coil L_2 has practically no reactance at the oscillation frequency, and serves simply as a connecting lead. The neutralizing capacitor C_n is now

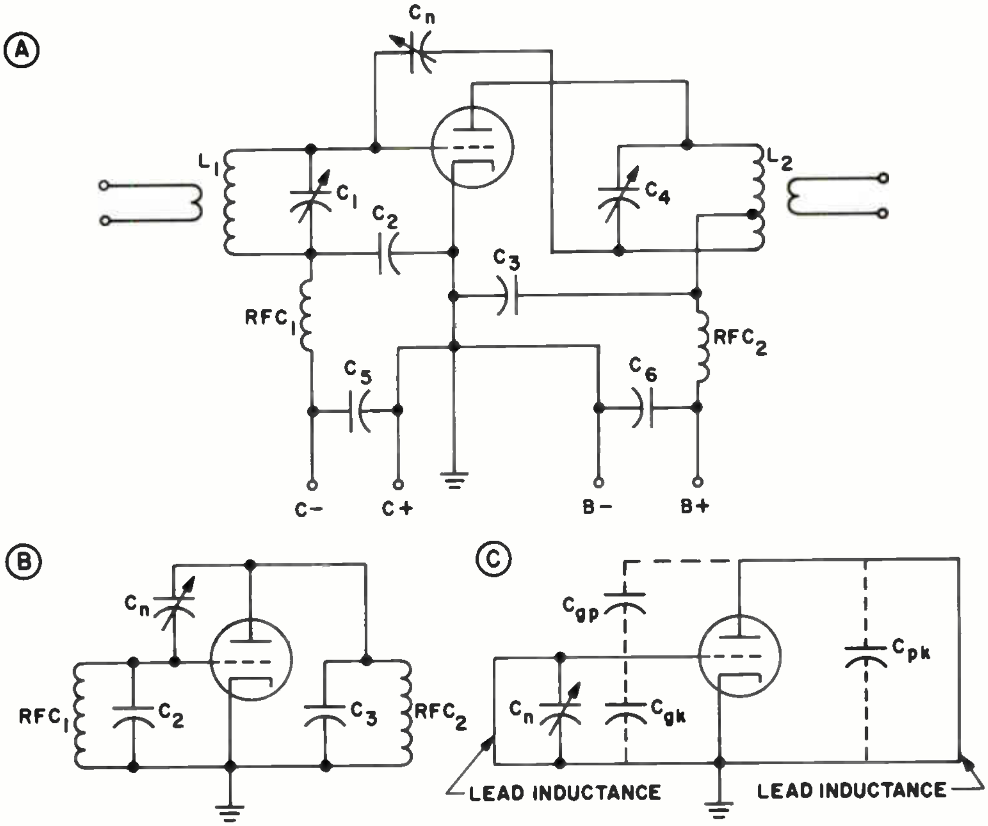


Fig. 20. A typical class C stage is shown at A; the effective circuit that produces low-frequency parasitics is shown at B; the effective circuit that produces high-frequency parasitics is shown at C.

effectively in parallel with the tube grid-plate capacity and increases rather than reduces feedback. Coils L_1 and L_2 do have a slight reactance at the parasitic frequency, so tuning capacitors C_1 and C_4 can make slight changes in the parasitic oscillation frequency.

The effective circuit for the stage, if it were producing high-frequency parasitic oscillations, is shown in Fig. 20C. In this case, the grid and plate circuits are tuned by the inductance of the leads between the tube elements and the tank circuits and the grid-to-cathode capacities. At the high frequencies, the capacities of C_1 and C_4 are so high that they act only as connecting leads in the inductive circuit. Capacitors C_2 and C_3, which are even larger in size, have practically no reactance at this frequency. The neutralizing capacitor C_n now appears between grid and ground and is effective in determining the frequency of the grid circuit. Feedback is through the capacity between grid and plate.

Preventing Parasitics. In the effective circuit of either Figs. 20B or 20C, parasitic oscillation can be prevented by making the resonant frequency of the grid circuit higher than that of the plate circuit. This may be done in Fig. 20B by making capacitor C_2 smaller than C_3 or by making R_FC_1 smaller than R_FC_2.

The most satisfactory method for suppressing very high-frequency parasitic oscillations in a class C amplifier stage is by using parasitic suppressors. The purpose of these parasitic suppressors is to increase the circuit losses at the parasitic frequency. Examples of these suppressors are shown in Fig. 21.

The suppressors are low resistances, usually around 100 ohms, in parallel with small rf chokes. At the normal operating frequency, these small coils, L_1 and L_2, have very low inductive reactances, and the signal frequency can pass through them with no loss. At the frequency of the parasitic oscillation, however, these coils have very high reactance and force the parasitic signal to flow through resistors R_1 and R_2. The loss of parasitic signal in the two resistors is great enough to prevent the tube from going into oscillation at these high frequencies.

Although a commercially manufactured transmitter should be free of parasitic oscillations, occasionally a new transmitter being tuned up for the first time will have them. Parasitics can also occur if parts are replaced by those of a different make. Whenever modifications are made in an amplifier stage, that stage should be checked for both high and low-frequency parasitics. Low-frequency parasitics will sometimes be evident as sidebands of the carrier frequency. The most common indication of high-frequency parasitics is an unusually high plate current and low output.

MULTIELEMENT TUBE STAGES

In a previous lesson you learned about the characteristics of screen grid, pentode, and beam-power tubes. Let us review briefly their characteristics with respect to their use as class C amplifiers.

If a tetrode or pentode tube is used in the stage, the screen grid of the tube acts as an electrostatic shield between the grid and plate, which reduces the grid-to-plate capacity. Therefore, tetrode and pentode tubes are less susceptible to feedback and self-oscillation, and usually do not require neutralizing.

Multielement tubes have a higher power gain than triodes. In other words, for the same amount of grid driving

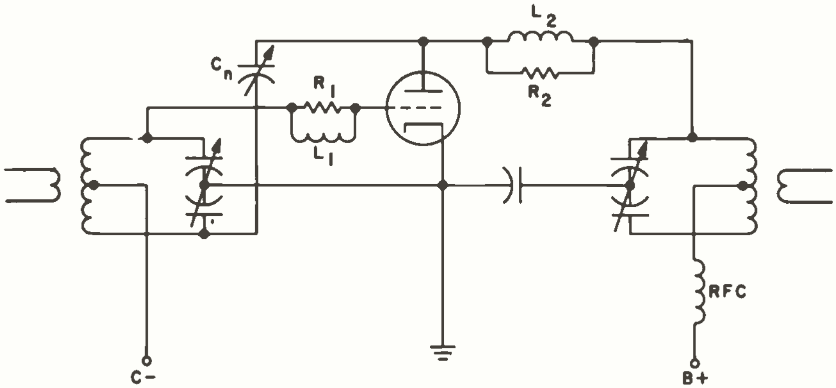


Fig. 21. Parasitic suppression methods.

power, you can get a higher power output from a stage using a multigrid tube than from one using a triode. This means that fewer stages are needed to get the desired power output. It also means that better shielding must be used between input and output circuits to prevent external feedback. Even a very small amount of feedback from the output of a stage back to the input can cause oscillation. Also because of the higher power gain, parasitic oscillations are more common in tetrode and pentode stages than in triode stages.

In screen-grid (tetrode) class C amplifiers, the minimum plate voltage must not be allowed to swing lower than the screen voltage because the screen then offers a greater attraction to the electrons than the plate. The secondary emission effect, due to electrons bouncing off the plate and being pulled to the screen instead of falling back onto the plate, determines the minimum the plate voltage can swing to. The grid excitation is adjusted so that the grid swings far enough positive so that the tube draws maximum permissible peak plate current without exceeding the dissipation rating of the plate and grid electrodes.

A pentode tube permits a greater plate voltage swing and, therefore, an even higher power gain. It does so by using a suppressor grid at cathode potential between the plate and screen grid to prevent secondary electrons from moving to the screen grid. Thus, the plate current remains independent of plate voltage to a much lower value of plate voltage. The suppressor grid forces the secondary electrons coming off the plate to return to the plate.

A beam-power tube has characteristics similar to those of a pentode. The tube elements are shaped in such a way that they control the electrons flowing between the cathode and the plate of the tube. Proper shaping of the electrodes sets up a potential barrier between screen and plate to suppress secondary emission.

You will find many multielement tubes used in transmitter equipment because of their higher power gain and simplicity of neutralization. Beam-power tetrodes are the most common.

In many circuits using multielement tubes, no neutralization is used. However, the power gain of these tubes is so great that only a small amount of feedback will set up instability and oscillations. Keeping feedback below the level that will cause instability or oscillation is a real problem. Even if a stage does not oscillate when it is first manufactured, there is no guarantee it will not be unstable when the tube in the stage is replaced. To overcome these problems, manufacturers often neutralize stages using multielement tubes.

In a class C stage using a multielement tube, the screen voltage has as much control, or more, on the plate current and power output as the actual value of the plate supply voltage. The plate supply voltage, however, must be high enough to obtain the necessary plate voltage swing across the plate-tuned circuit. Because the screen grid has so much control, the power output in some transmitters is controlled by varying the screen grid voltage.

The correct voltage must be applied to the plate of a multigrid tube at all times. If the plate voltage drops to zero or is lower than normal, the screen grid may be damaged. Under these conditions the screen current may be so high that it exceeds the safe dissipation factor.

Screen voltage and current also vary with the grid excitation, particularly if the screen voltage is obtained through a dropping resistor. An increase in grid excitation will cause the screen current to rise and the screen voltage to fall. A decrease in excitation will have the opposite effect.

When a tetrode or pentode stage is being tuned and loaded, the plate and screen voltages should be reduced. Most transmitters using tetrode or pentode power stages have provisions for reducing these voltages during tuning. A nonresonant or unloaded plate tank causes the minimum plate voltage to drop below the screen voltage. Under these conditions, the screen draws excessive current. This may destroy high-power tetrodes in a matter of a few seconds. After the tuning and loading are roughly adjusted, full voltage can be applied to the tube and the adjustments carefully peaked.

MULTITUBE STAGES

To get a higher output from a class C stage, two tubes can be connected in parallel, or in push-pull. For very high power, tubes are operated in push-pull-parallel; that is, two sets of parallel-connected tubes are operated in push-pull.

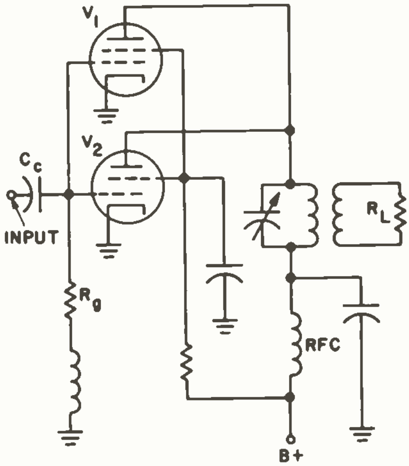


Fig. 22. Class C amplifier with two tetrodes connected in parallel.

Parallel Operation. Fig. 22 shows a stage with two tubes connected in parallel. In parallel operation, the output power is approximately twice that from a single tube, if the correct driving power is applied and the circuit components and electrode voltages have the correct values.

The grid current is doubled, because with two tubes the grid impedance is approximately halved. The driving power needed for the parallel amplifier is twice that needed for a single tube.

When grid-leak bias is used with the class C stage, the value of the grid resistor must be cut in half to get the same grid bias at twice the grid current.

The internal or plate resistance is also halved because of the parallel connection and doubling of the peak plate current. Thus, the same tuned circuit voltage is developed with twice the plate current. It is the higher amplitude plate current pulses exciting the tuned circuit that develop the added power delivered to the load in parallel operation.

Push-Pull Operation. A push-pull amplifier is shown in Fig. 23. The input excitation is applied with equal amplitude but opposite polarity to the grids of the push-pull stage. The ground point of the circuit is at the center of a split-stator variable capacitor.

As in the case of parallel tube operation, the grid and plate currents drawn are twice as great as those drawn by a single tube. To retain balanced operation of the push-pull stage where each tube performs an equal share of the work, the supply voltages are applied at the mid-

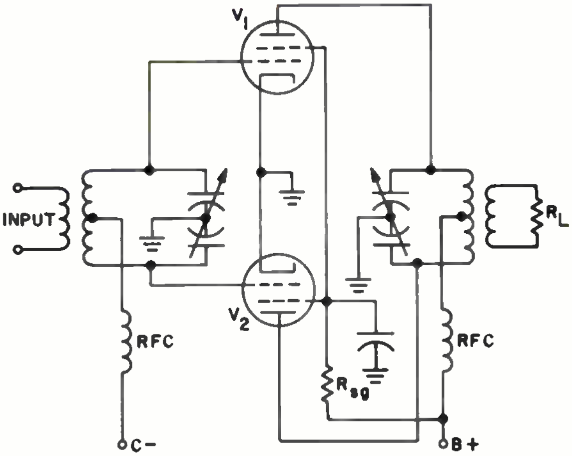


Fig. 23. Push-pull class C amplifier using tetrodes.

points of the coils so as not to imbalance the stages.

Balanced operation is necessary to prevent possible overloading of one of the tubes because of any uneven dissipation of power by the grid or plate. Imbalance can be caused by tubes that are not exactly matched or by a mismatch between the grid or plate circuit components. Thus, both the circuits and the tubes must be matched and balanced to get proper operation of the stage.

FREQUENCY MULTIPLIERS

A frequency multiplier stage is a class C amplifier that is used to generate an output signal whose frequency is some multiple of the applied signal frequency. For example, the frequency of the output of a doubler stage is twice the frequency of the input. The frequency of the output of a tripler is three times the frequency of the input. A doubler with an input frequency of 10 MHz would have an output signal of 20 MHz. A tripler with an input frequency of 10 MHz would have an output signal of 30 MHz. Multipliers can be used to generate signals of even higher multiples of their input signal frequency, but the higher the multiplication the lower the output. Thus, you can expect less output from a tripler than from a doubler using the same tube type. A multiplier generating a signal four times the frequency of the input signal would have an even lower output than a tripler using the same tube.

When a tank circuit is shock-excited into oscillation by a single current pulse, the circuit will continue to oscillate for a number of cycles. The number of cycles will depend on the losses in the circuit. Each cycle will be lower in amplitude than the preceding one because of these losses. With a high Q circuit, when the losses are low, there will be many cycles before the oscillation drops to zero.

In a frequency multiplier we take advantage of the fact that oscillation, once started, will continue for many cycles in a tank circuit. By using a tank circuit in the plate circuit of the tube that is resonant at some multiple of the input frequency, we can start the oscillation by feeding an rf signal to the grid. This will produce a plate current pulse that starts the tank circuit oscillating at its resonant frequency which may be two or three times the frequency of the input signal. This oscillation would soon die out, except on the second cycle, in the case of a doubler, or the third cycle in the case of a tripler, where the grid of the tube will be driven positive again by the rf signal. This produces another plate current pulse which adds to the energy in the tank circuit and supplies the power needed to make up the circuit losses, so the oscillation in the plate circuit continues. Now let's look at some typical frequency multiplier circuits.

Single-Tube Multipliers. The circuit of a frequency multiplier is very simple; one is shown in Fig. 24. It is even simpler than a regular class C amplifier. No neutralization is needed, even when the tube used is a triode, because self-oscillation occurs only if the input and output circuits are tuned close to the same frequency. In a doubler the output tank circuit is tuned to twice the frequency of the input circuit, in a tripler it is tuned to three times the frequency, etc.

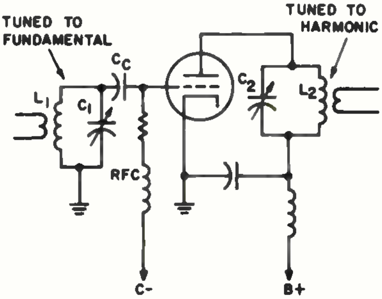


Fig. 24. Basic frequency-multiplier stage.

The current waveforms in the tank circuit of a class C amplifier are compared with those in a frequency multiplier in Fig. 25. Fig. 25A shows the waveforms for a fundamental class C amplifier. The plate current pulse flows during part of each cycle of the incoming signal. The flywheel action of the tank circuit develops the fundamental sine wave output, shown by the dashed curve.

Fig. 25B shows the waveforms for a single-tube doubler circuit. The tube is

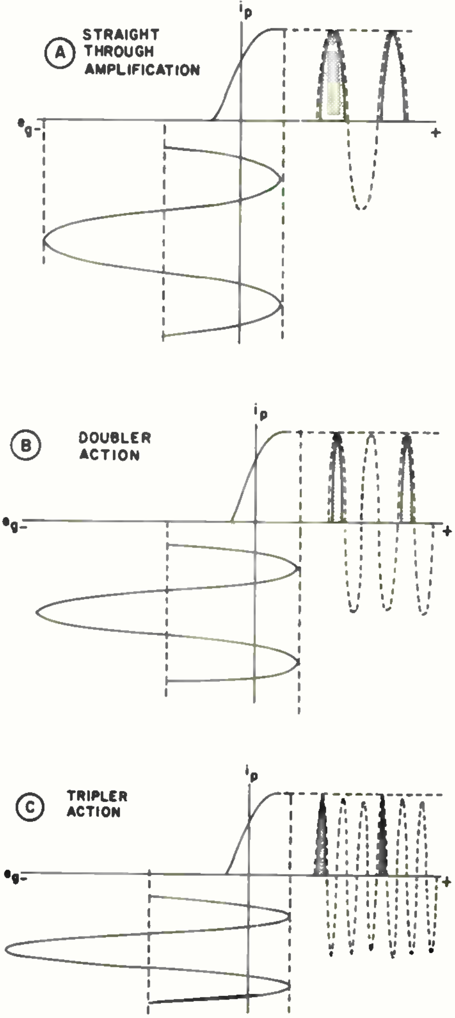
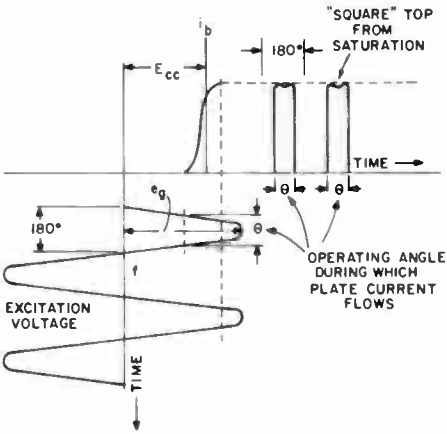


Fig. 25. Waveshapes of frequency multipliers compared to the "straight-through" amplifiers.

operated with a higher bias, so the plate current pulse flows during a smaller part of each cycle of the incoming signal, and the flywheel action of the resonant circuit carries through that cycle and another cycle before the next plate current pulse arrives. Since the plate current flows only on alternate cycles of the output, the power output and efficiency of the stage are lower than for fundamental operation. The efficiency is usually less than 50%.

The higher the harmonic signal to which the tank circuit is tuned, the lower the obtainable power output and efficiency of the class C stage. Fig. 25C shows the waveforms for a tripler. The tube is biased so that the plate-current flows a still smaller part of the cycle of the incoming signal, and the resonant circuit carries through three cycles before the next pulse arrives. Losses in the circuit cause the amplitude of each succeeding cycle to decrease. The efficiency of a tripler stage is even less than that of a doubler. The efficiency of a multiplier is kept as high as possible by using the proper values of L and C in the tank circuit and correctly shaping the plate current pulse.

The best pulse shape is a square top pulse like the ones shown in Fig. 26. This pulse shape can be obtained by operating the stage with a high bias and then driving the stage to plate-current saturation. For best doubler operation, the angle of current flow, indicated by the Greek letter θ (theta), should be somewhere between 90 and 120 degrees. With this angle of flow, the plate current pulse has a suitable and effective second harmonic content. For tripler operation, the angle of current flow is reduced to less than 90 degrees, and the third harmonic component is emphasized.



OUTPUT FREQ	OPTIMUM OPERATING ANGLE (θ)
2f	90°—120°
3f	80°—100°
4f	70°—90°
5f	60°—70°

Fig. 26. Multiplier operating characteristics.

The plate tank circuit of frequency multipliers can usually be tuned over a wide enough range to resonate at more than one harmonic of the signal at the grid. Therefore it is important that you check the output frequency to be sure you have the correct harmonic. You can do this with an absorption wavemeter. You'll learn more about this instrument later in the lesson.

Two-Tube Multipliers. A special higher powered and somewhat more efficient doubler can be obtained by using the push-push arrangement shown in Fig. 27A. In this circuit, the grids are supplied with signals in push-pull and the plates are connected in parallel.

The tubes are connected so that one will conduct on the positive alternation of the incoming signal, shown in dashed lines in Fig. 27B, and the other tube will conduct on the negative alternation.

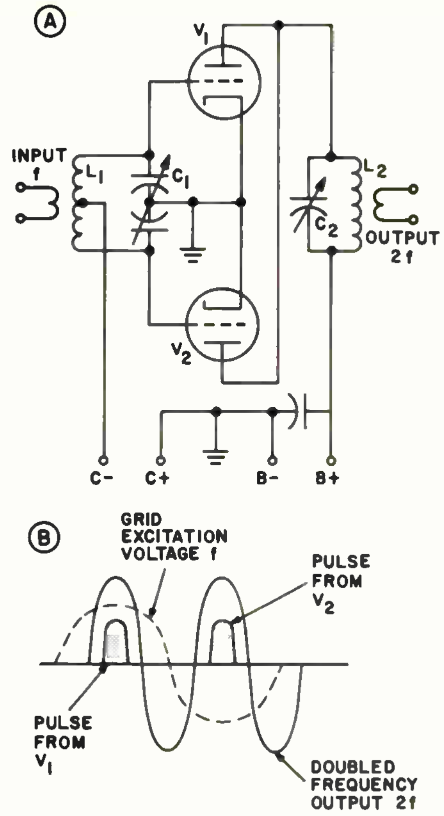


Fig. 27. Push-push doubler for even harmonics.

Thus, plate current pulses are fed to the output circuit once during each alternation of the doubled frequency. The efficiency and power output are higher than for a single-tube doubler.

The push-push frequency multiplier stage in Fig. 27A operates well on even harmonics, but not on the fundamental or odd harmonic frequencies. Frequency doublers are used more often in transmitters, especially low-frequency transmitters, than the higher harmonic generators because of the higher output and efficiency. The grids are connected in push-pull, so they must be fed with balanced signals to get the proper output signal.

Since the doubler is the most frequently used type of frequency multiplier stage, let us list some of its characteristics:

1. The plate tank circuit is tuned to twice the grid circuit frequency.
2. It does not have to be neutralized.
3. The operating angle of the plate current pulse is approximately 90°.
4. The dc bias is about 10 times the plate current cutoff value.
5. The plate current pulse has a greater harmonic content.
6. It requires a very large grid-driving signal.
7. It has a low plate efficiency compared to a fundamental class C amplifier.

As you can see, some of these characteristics vary widely from those of a class C amplifier operating as a fundamental frequency amplifier.

SELF-TEST QUESTIONS

(l) What is the disadvantage of using only grid-leak bias in a class C amplifier?

(m) What is the feedback path for oscillations near the operating frequency in a triode class C amplifier?

(n) What is the main advantage of plate neutralization over the method of connecting a coil and blocking capacitor from plate to grid?

(o) In Fig. 16, what is the phase relationship between the signal fed through C_N and the signal fed back through grid-plate capacitance?

(p) What inductive components in the grid circuit form part of the low-frequency parasitic resonant circuit?

(q) What might be the cause of unusually high plate current and low rf output from a transmitter?

(r) What two characteristics of tetrodes make them more useful as class C amplifiers than triodes?

(s) What characteristic of tetrodes make them more susceptible to parasitic oscillation than triodes?

(t) How would the values of L and C in a tank used in a parallel-connected stage compare with those used in a similar single tube circuit operating at the same frequency?

(u) How is balanced operation obtained in a push-pull stage?

(v) In general, which multiplier would have a higher output, a doubler or a tripler?

(w) Why are neutralization circuits unnecessary in a triode operated as a frequency multiplier?

Transistor Power Amplifiers

In their present state of development, transistors cannot amplify high-frequency signals to high power levels as well as vacuum tubes. However, power outputs greater than 100 watts or frequencies much above 400 MHz are seldom required in many communications applications. Chief among these is commercial mobile radio. In this application, the transistor's small size, low operating voltage, extreme ruggedness, and high overall efficiency make it ideally suited for use in mobile radio equipment.

The common emitter circuit is almost universally used for transistor rf power amplifiers because of its greater stability at radio frequencies. This circuit arrangement is often compared with the grounded cathode triode. As you might expect, it has much in common with the triode circuits you previously studied. With transistor amplifiers we are concerned with the biasing, efficiency, and stability, just as we were with the triode. In this section, we'll look at some typical circuits which illustrate the important features of transistor rf power amplifiers.

BIASING METHODS

You have learned that class C operation of a power amplifier results in the highest percentage of input power being converted to useful rf energy at the output. In the case of a transistor, where high-frequency power handling is a limitation, we are especially interested in getting the highest efficiency obtainable from the stage. It is not surprising, then, that most transistor rf amplifiers are operated class C.

Two practical methods of obtaining bias for class C operation are shown in Fig. 28. The circuits illustrated employ NPN transistors; PNP devices could just as well have been used (with all polarities reversed, of course).

In Fig. 28A, reverse bias across the emitter base junction is developed by the R_1-C_1 network in the emitter circuit. When the input signal to the stage goes sufficiently positive, base and collector currents flow over the paths indicated by the solid lines. Both these currents flow through the emitter resistor, dropping a voltage of the polarity indicated. Capacitor C_1 charges to the peak value of this voltage drop. During the time between positive-going portions of the input signal, C_1 slowly discharges through R_1

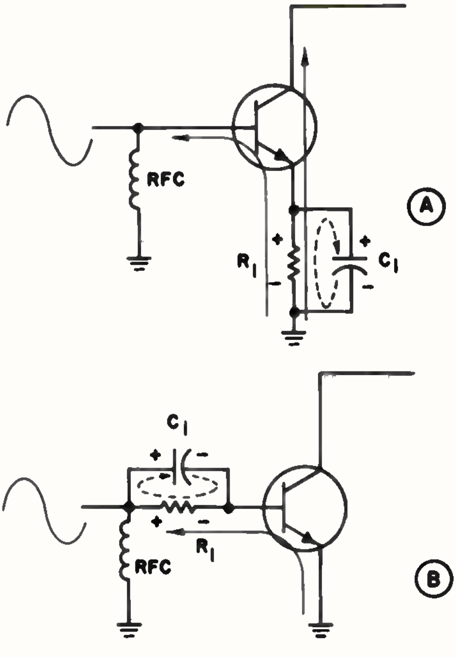


Fig. 28. Methods of obtaining emitter-base reverse bias.

as indicated by the dashed line. The values of R_1 and C_1 are such that C_1 does not discharge appreciably before the input signal again swings positive, thereby recharging C_1. The emitter is thus maintained slightly positive with respect to the base by the charge across C_1. Collector current does not flow until the input signal drives the base more positive than the emitter.

Reverse bias for the circuit of Fig. 28B is developed in the base circuit, again by a parallel combination of R_1 and C_1. The base current drawn during the positive-going portion of the input signal (indicated by the solid line) drops a voltage across R_1 as shown. C_1 charges to the peak value of this voltage drop and essentially maintains its full charge during the time between positive-going portions of the input signal. This is possible because the discharge path for C_1 (shown by the dashed line) is through R_1, the value of which is chosen to permit only a very small discharge current to flow. Notice that the polarity of the charge on C_1 is such that it subtracts from the positive-going portion of the input signal. This means that the input signal voltage must exceed the voltage across C_1 before the emitter base junction becomes forward-biased, allowing collector current to flow.

The two circuits shown in Fig. 28 depend on the presence of an input signal to develop bias. With no input signal present, zero bias is developed. Unlike vacuum tubes, however, transistors do not conduct under zero bias conditions and are therefore self-protecting.

Not only are transistors nonconducting under zero bias conditions, but also a small forward-biasing voltage must exist across the emitter base junction before collector current begins to flow. Fig. 29 shows collector current plotted against emitter-to-base voltage for a typical rf power transistor.

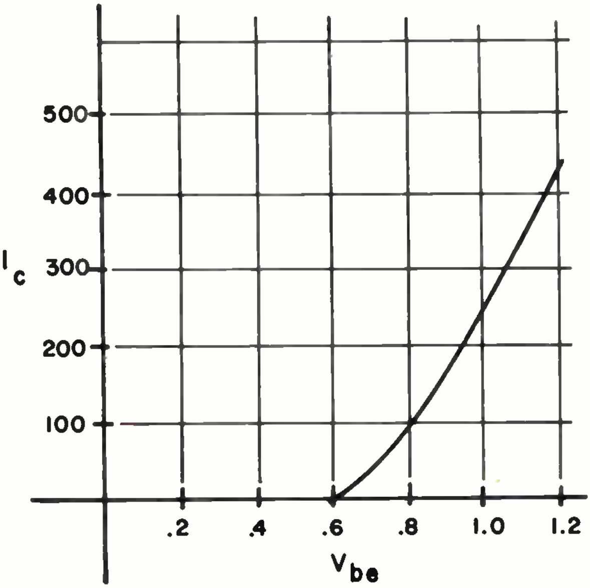


Fig. 29. Collector current plotted against emitter-to-base voltage of a typical RF power transistor.

As you can see from the graph, collector current does not begin to flow until the emitter-base voltage reaches approximately .6 volts. When we operate a power transistor with zero bias, then, we are actually biased about .6 volts below collector current cutoff.

Fig. 30 shows the graph of Fig. 29 with an input signal of 1 volt peak amplitude applied. Collector current flows only during the time the input signal is above .6 volts. The conduction angle here would be about 120° of the input cycle, well within the class C operating range. Input signal levels of such low amplitude are not unusual in power transistors because of the transistor's low input impedance. Input impedances actually range from several ohms to less than 1 ohm. With such a low input impedance, a relatively large input current is permitted to flow when the base-emitter junction of the transistor is driven positive.

Recalling that P = EI, you can readily see that the driving power to the stage is accounted for primarily by the high current flow which develops only a small voltage across the low input impedance. It follows, then, that a reverse-biased emitter-base junction is not always necessary for class C operation.

MULTITRANSISTOR AMPLIFIERS

As mentioned earlier, the power obtainable from a transistor used as an rf amplifier is rather limited as compared to vacuum tubes used in similar circuits. When more power is required than can be obtained from a single transistor, several transistors can be arranged in push-pull or parallel. In a push-pull arrangement, an input transformer is required to feed the transistors out-of-phase signals. This transformer is also required to match the relatively high output impedance of the

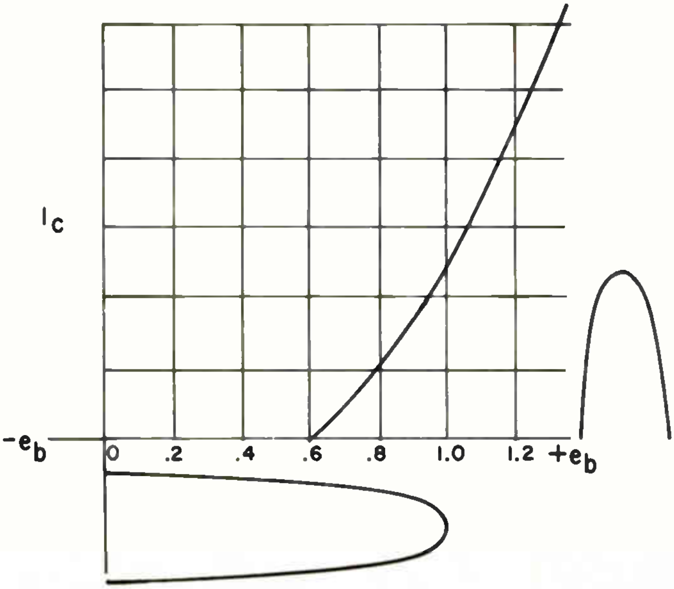


Fig. 30. Curve of Fig. B with signal applied showing collector current pulse.

driver to the very low input impedance of the push-pull stage. Such a transformer capable of operation at high frequencies is very expensive to build. For this reason, multiple transistor stages are nearly always parallel-connected.

Fig. 31 shows a two-transistor parallel-connected rf amplifier stage. C_1 and L_1 form an L network which provides the proper impedance match between the source and the input to the stage. The input signal is developed across RFC_1, amplified by the transistors, and applied to the load through the output coupling network. Notice that we can vary the operating bias of the two transistors by adjusting R_1 and R_2. These adjustments are necessary so that the two transistors will share the load equally. In practice we would insert a milliammeter in the collector or emitter circuit of each transistor and adjust R_1 and R_2 for equal currents. With the currents balanced, each transistor will be handling half of the power delivered to the output coupling network. C_4 is a coupling capacitor and may be considered a short circuit at the operating frequency. The output coupling circuit is a pi network consisting of C_5, L_2, and C_6. C_5 and C_6 are adjusted to provide the proper collector load and circuit Q for the transistors.

Another circuit employing transistors in parallel is shown in Fig. 32. Besides containing three transistors instead of two, this circuit differs from the one in Fig. 31 in two other important respects. First of all, load balancing is obtained by adjusting L_1, L_2, and L_3 in the base circuits. These adjustments vary the rf

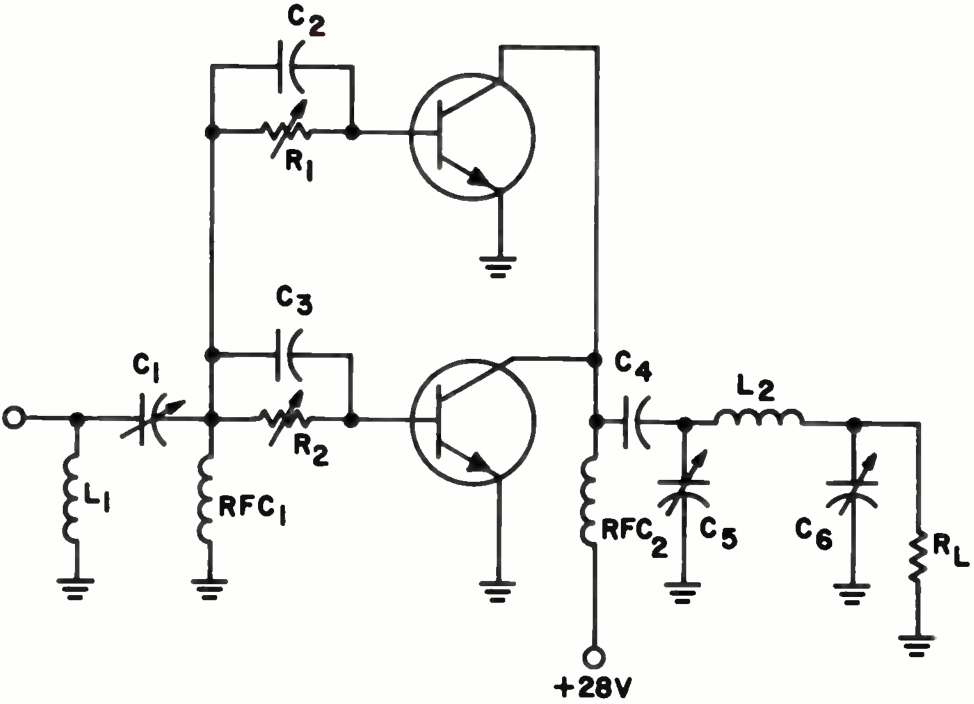


Fig. 31. Two-transistor parallel-connected RF amplifier.

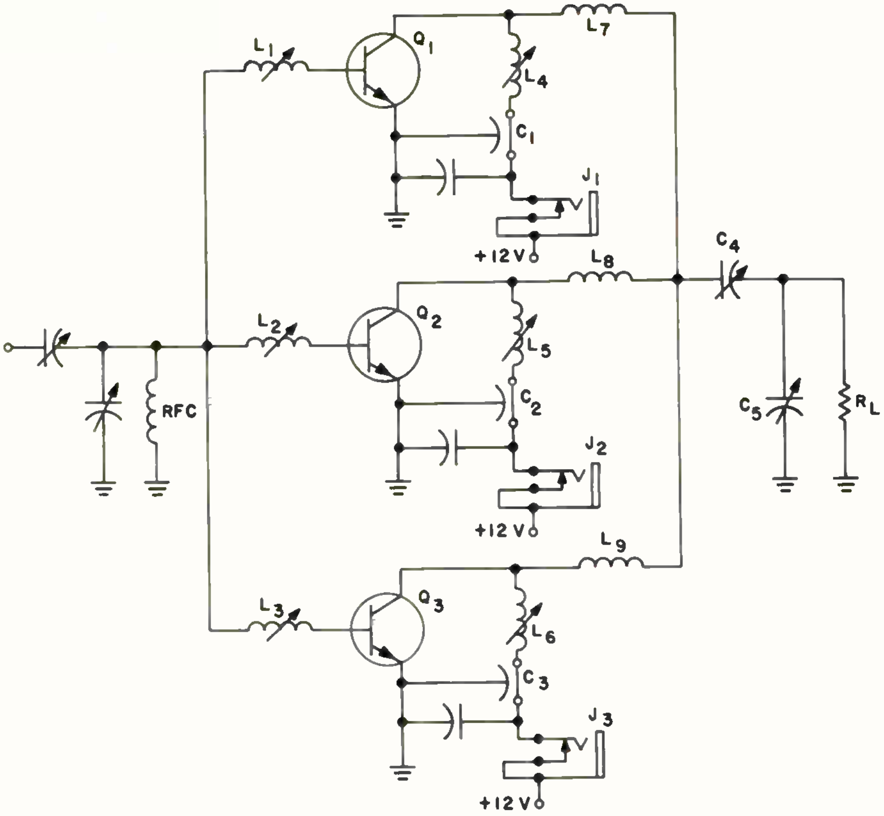


Fig. 32. Three-transistor parallel-connected RF amplifier.

drive to the transistors and equalize the load currents as previously discussed. Secondly, each of the three transistors in Fig. 32 has a separate output tank circuit connected to a common load as in Fig. 31.

The tank circuit for Q_1 is made up of L_4, L_7 and stray capacity. L_5 and L_8 are the tank inductances for Q_2; L_6 and L_9 are the tank inductances for Q_3. These tank circuits are also tuned by stray capacity. The right-hand ends of L_7, L_8 and L_9 connect to C_4 which, along with C_5, varies the coupling from the three tank circuits to the load R_L.

There are two reasons why separate tank circuits are used for the three transistors. First, each transistor is series-fed, thus eliminating the losses and other problems of an rf choke. Second, the dc collector currents are entirely separate so each transistor can operate essentially independent of the other transistors. Thus, if some trouble developed in Q_1, this stage could be disconnected and the amplifier could continue to operate at a lower power level. Directly paralleled stages would have to be completely retuned if one stage were to be removed.

Many rf power transistors have their emitters internally connected to the transistor case. This is done to eliminate the stray inductance of the emitter lead. When the case is connected to ground, as it would be in a circuit such as that shown in Fig. 32, current could not be conveniently measured in the emitter circuit. The use of separate collector loads, however, enables convenient monitoring of collector current. In Fig. 32, the jacks labeled J_1 through J_3 are provided for this purpose.

The symbol used to represent C_1 through C_3 may be unfamiliar to you. This is a special type of capacitor called a feed-thru and is often used for bypassing in high-frequency circuits. As the symbol suggests, one plate of the capacitor completes a dc path in the circuit; the other plate, usually connected to ground, surrounds the first much like the braided shield in a piece of coaxial cable.

FREQUENCY MULTIPLIERS

Fig. 33 shows two transistor frequency multiplier stages coupled together. The output of the tripler, Q_1, feeds a doubler, Q_2, to give a total frequency multiplication of six. The input signal, which we've designated as F_O, is applied to the base of Q_1. With the drive signal present, R_1 and C_1 develop a relatively high reverse bias across the emitter base junction. The high reverse bias results in a narrow conduction angle and collector current pulses with a high harmonic content. The collector tank is tuned to the third harmonic, $3F_O$, and offers a high impedance only at this frequency.

Signals at the fundamental, as well as those at other harmonics, are bypassed to ground by C_2 and C_3. The signal at the frequency $3F_O$ is inductively coupled into the base circuit of Q_2. Reverse bias for Q_2 is developed by the driving signal in a manner similar to that described for Q_1. The collector tank for Q_2 is tuned to $6F_O$ and inductively couples the signal at this frequency into the load. Undesired signals are again bypassed to ground, in this stage by C_5 and C_6.

While individual stages are seldom designed for frequency multiplications greater than three, any desired total multiplication may be obtained by connecting multipliers together. The usual arrangement in a transmitter is a straight-through class C amplifier following each one or two multiplier stages. In this

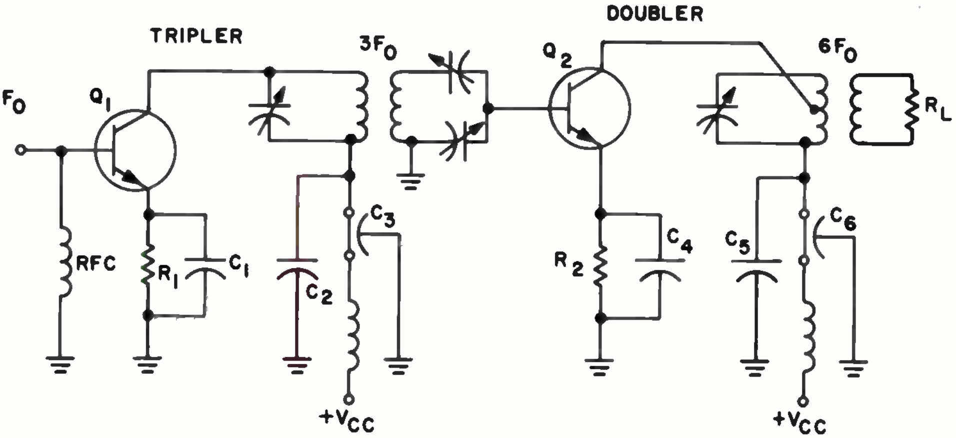


Fig. 33. Two frequency multiplier stages coupled together.

manner, the relatively low output from the multiplier is built up before being applied to the next multiplier. The straight-through amplifier also offers additional suppression to the undesired harmonics generated in the multiplier stage.

AMPLIFIER STABILITY

You learned that, in the triode power amplifier, in-phase feedback through plate-to-grid interelectrode capacitance could cause the amplifier to oscillate. To prevent these oscillations from occurring, components were added to feed back an out-of-phase voltage of equal amplitude and thus "neutralize" the interelectrode capacitance of the tube.

A similar capacitance exists between the collector and base of a transistor. However, the value of this collector-to-base capacitance in power transistors is voltage-dependent. That is, as the reverse bias across the collector base junction varies (which it normally does over the period of an operating cycle) the collector-to-base capacitance also varies. To be effective, a neutralizing circuit for a power transistor would have to continuously adjust itself to this variation. Because of this requirement, neutralization of a transistor rf amplifier is normally not practical. Instead, the need for neutralization is usually eliminated by careful circuit design using transistors with low values of interelement capacitance.

Parasitics. In the radio frequency range, the power gain of a transistor falls off rapidly as frequency increases. This characteristic of transistors works to advantage in preventing parasitic oscillations above the operating frequency. At these higher frequencies, the transistor has insufficient gain to overcome the circuit losses and sustain oscillations.

On the other hand, the power gain of a transistor is higher at the lower frequencies. To illustrate this, let's assume we have an rf power amplifier operating at 175 MHz. A typical transistor operating at this frequency might have a power gain of 5 db. This same transistor could have a gain as high as 30 db at 10 MHz. In other words, the power gain of the device is over 300 times greater at 10 MHz, the parasitic frequency, than at 175 MHz, the operating frequency. Consequently, the most common cause of instability in these power amplifiers is parasitic oscillation below the operating frequency.

The amplifier circuit shown in Fig. 34 illustrates a number of techniques used to prevent low frequency parasitics. These are discussed in the following paragraphs.

The rfc connected between base and ground (1) will at some frequency form a parallel-resonant circuit with the emitter base capacitance. To decrease the efficiency of this parasitic tank circuit, the rfc is designed to have a very low Q (high effective series resistance). Often this rfc is nothing more than a wire-wound resistor.

The emitter bypass capacitor (2) used is the smallest value which will provide effective bypassing at the operating frequency. At frequencies below the operating frequency, the reactance of this capacitor increases, resulting in degenerative feedback at these lower frequencies. This degeneration reduces the gain of the amplifier to low frequency parasitics.

The output coupling network is designed to include a portion of the network inductance in the collector dc supply line (3). With this arrangement, no

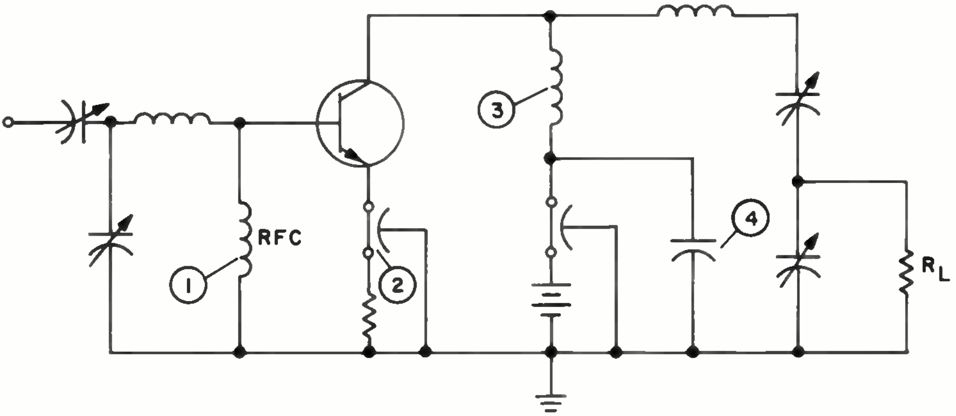


Fig. 34. Transistor power amplifier showing components used to prevent low frequency parasitics.

rfc is required in the collector circuit. Elimination of the collector rfc is desirable because this component can form a parallel-resonant circuit with the output capacitance at some relatively low frequency, thus becoming a possible source of low-frequency parasitics.

In addition to the feed-thru capacitor designed to bypass the power supply at the operating frequency, a second capacitor of larger value (4) provides a short circuit to ground at lower frequencies where parasitics usually occur. You might wonder why a larger capacitor, since it bypasses well at lower frequencies, wouldn't provide an even better bypass at the operating frequency where its X_c would be even less. The reason is that at higher radio frequencies the inductive reactance of the capacitor's leads becomes significantly large. The capacitor, instead of being a short circuit to ground, becomes an impedance to ground at these higher frequencies. The feed-thru capacitor, because of its physical construction, has very low lead inductance, and therefore provides an effective short circuit to ground at the high operating frequency. Feed-thru capacitors can only be manufactured with comparatively small values of capacitance, hence the need for the more conventional larger capacitor for the low-frequency bypass.

Fig. 35 summarizes what we have said about power supply bypassing. Shown in the figure are the equivalent bypass circuits for both the high operating frequency and the low parasitic frequency. At the operating frequency, the larger

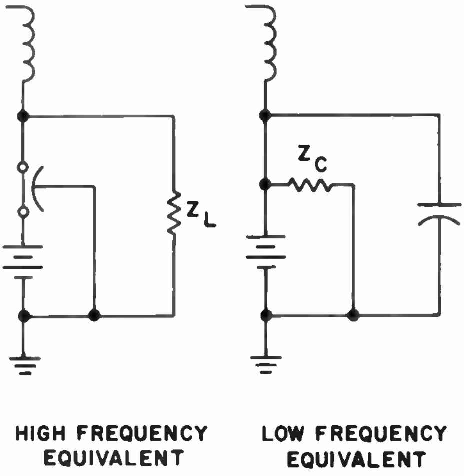


Fig. 35. Equivalent circuits for the power supply bypassing arrangement shown in Fig. 33.

capacitor appears as an inductive reactance, Z_L, and the feed-thru as an ac short circuit to ground. At a low parasitic frequency, the feed-thru appears as a high capacitive reactance, Z_C and the larger capacitor provides the ac short to ground.

SELF-TEST QUESTIONS

(x) Which transistor circuit configuration has the greatest stability at radio frequencies?

(y) What happens when loss of drive causes the bias on a transistor rf amplifier to drop to zero?

(z) Is reverse bias on the emitter base junction necessary for class C operation in a transistor rf amplifier?

(aa) What characteristic of transistor rf power amplifiers accounts for the low signal voltage developed in the input circuit?

(ab) Why is a parallel connection of transistors favored over a push-pull connection?

(ac) What are two advantages of having separate collector tank circuits for a parallel-connected transistor rf amplifier?

(ad) Why are feed-thru capacitors used for bypassing in high-frequency circuits?

(ae) What characteristic of power transistors makes neutralization impractical?

(af) What is the most common form of transistor rf amplifier instability?

(ag) Why is an additional capacitor placed in parallel with the feed-thru capacitor bypassing the power supply in Fig. 32?

Adjusting Class C Amplifiers

Adjustments to class C amplifiers in transmitter stages are performed following repairs, or routinely to compensate for normal circuit aging. The adjustment procedures for all class C stages, either frequency multipliers, intermediate amplifiers, or power output stages are basically the same. There are variations, of course; when you tune a frequency multiplier, for example, you must make certain that the plate circuit is tuned to the desired harmonic frequency.

In this section, we will go through the complete adjustment procedure for both a vacuum tube and a transistor class C amplifier stage. You should realize that adjustments such as those described in this section may be performed only by a person having the necessary authority. To obtain this authority, he must hold the proper class of FCC License or be under the direct supervision of another person who does.

THE VACUUM TUBE STAGE

Fig. 36 shows a typical class C amplifier circuit. Notice that there are current meters in the grid and plate circuits and that voltmeters are used to measure the bias, filament, and plate supply voltages. A power output stage using a screen-grid

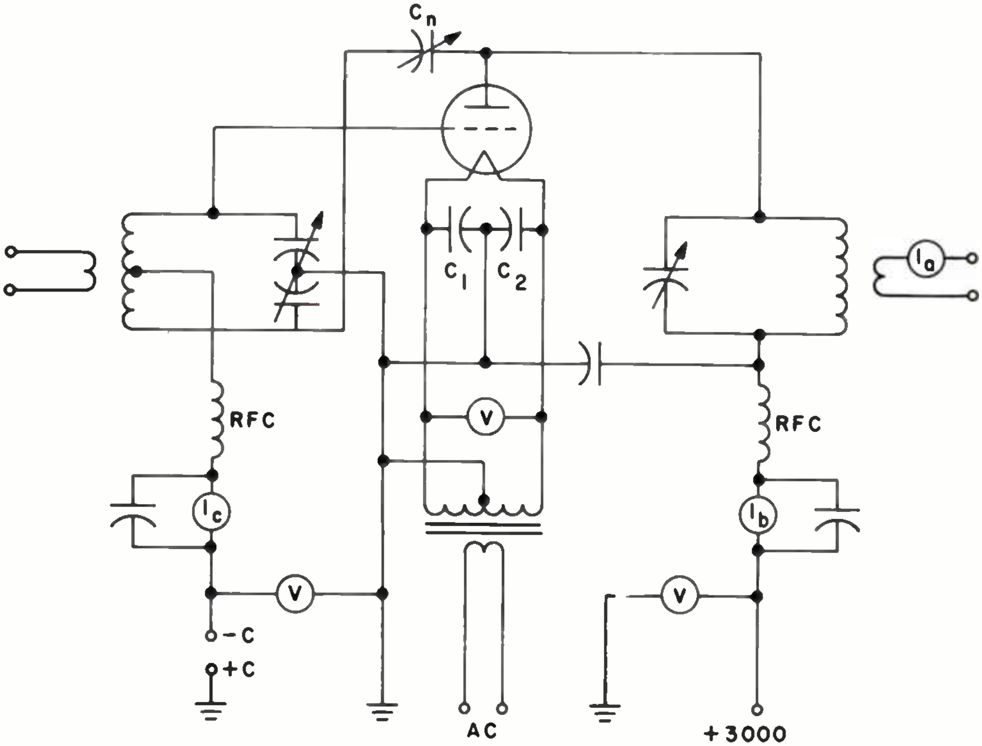


Fig. 36. Typical class C amplifier.

tube often has a current meter and voltmeter in the screen circuit. In some rf output stages, particularly in the low power exciter stages, only one voltmeter and one or perhaps two current meters are used. These meters are switched into the various stages to check the performance of the stage during operation or during the adjustment procedure.

Neutralization. The first step in the adjustment procedure is to insure that the amplifier is properly neutralized. Always check for neutralization with all interstage shields in place. If the amplifier is enclosed in a separate shield box within the transmitter cabinet, check it with the shield box closed. There will probably be stray magnetic or electrostatic coupling between output and input circuits unless all shields are in place and closed.

Neutralization can correct only for capacitive coupling directly from the grid to the plate of the tube. The simplest indication which can be used to determine correct neutralization is the grid current meter. With B+ removed from the stage, the need for neutralization will be indicated by a dip in the grid current when the plate tank is tuned through resonance. The grid current dips because the power loss in the resistance of the plate tank is greatest at resonance. Since this power is fed into the plate tank through the grid-plate capacitance, it subtracts from the grid current and causes a dip.

A second, more sensitive, method of checking for correct neutralization is by use of a wavemeter. As shown in Fig. 37, this simple device consists of a parallel L-C circuit connected to a diode and dc milliammeter. The variable capacitor, which is calibrated in units of frequency, may be adjusted to make the circuit resonant over a wide range of frequencies.

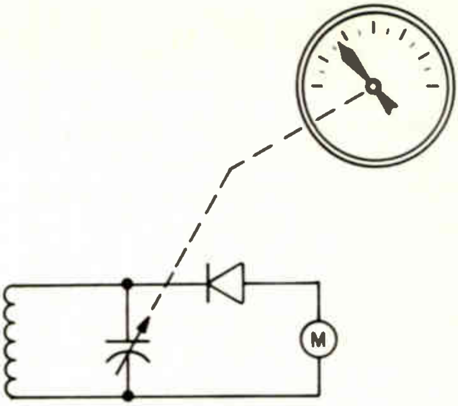


Fig. 37. Simplified schematic diagram of a wavemeter.

Any energy coupled into the tank circuit is rectified by the diode and causes the meter to deflect. In use, the wavemeter is inductively coupled to the plate tank circuit of the stage to be checked.

With plate voltage removed and grid drive applied to the stage, there should be no indication on the meter as the tuning knob is adjusted near the operating frequency. An indication on the meter indicates the presence of rf in the plate tank. This rf could only have come from the grid circuit -- coupled through interelement capacitance to the plate tank. Hence, the stage must be neutralized.

The procedure to be used in neutralizing an amplifier is as follows:

1. Remove the B+ from the stage. *Never attempt to neutralize an amplifier with the plate voltage connected.*
2. Set the neutralizing capacitor for minimum capacity.
3. Apply filament power and bias to the stage, and apply filament power, bias, and B+ to all stages ahead of the stage being neutralized.
4. Tune the grid circuit to resonance as indicated by maximum grid current.

5. Tune the plate tank circuit to resonance while watching the neutralization indicator. If it is a grid meter, it will dip; if you are using a wavemeter, it will peak.

6. Increase the capacity of the neutralizing capacitor slightly. Check grid and plate resonance; changing the neutralizing capacitor will sometimes detune both grid and plate circuits.

7. Continue to increase the neutralizing capacitance in small steps until there is no dip in the grid meter or no indication of power in the plate tank. The transmitter is then correctly neutralized.

As you come closer and closer to neutralization, make smaller and smaller changes in the neutralizing capacitor. There is only one correct setting; too much and too little capacitance are equally bad. Remember to retune both grid and plate each time you change the neutralizing capacitor. If the transmitter uses inductive link neutralization, start with maximum coupling to this link. Then reduce the coupling in small steps until you find the correct coupling.

Neutralization must be made as accurately as possible. Although steady oscillation will take place only when enough power is fed back from the output to overcome the input circuit losses, smaller amounts of feedback, which are not enough to cause steady oscillation, can still affect the operation of the stage. An amplifier operating like this is said to be "regenerative."

Several characteristics of an amplifier change when it is regenerative. One of the most pronounced is an increase in input impedance. This increase in impedance causes the Q of the grid and plate tuned circuits to increase also. The increase in Q makes the circuits selective and hard to tune. To make matters worse, changes in the plate tuning change the amount of feedback and, therefore, affect the grid tuning.

A regenerative amplifier is an unstable amplifier. A slight increase in filament current or plate voltage may cause it to go into steady oscillation. Reducing the load at the output will also cause oscillation.

In a keyed transmitter, a regenerative amplifier will cause damped oscillations every time the key is closed. As a result undesirable signals are generated. In a phone transmitter, an unstable amplifier causes still other effects.

Perfect neutralization of an amplifier is absolutely necessary. It takes time to do it right, but it does not have to be done often.

After you have completed the neutralizing procedure, apply a low plate voltage to the stage. Tune the plate tank capacitor to resonance as indicated by minimum plate current readings. You will notice that the plate current will dip sharply because the output tank circuit is not delivering power to the load. This is shown by the solid curve in Fig. 38.

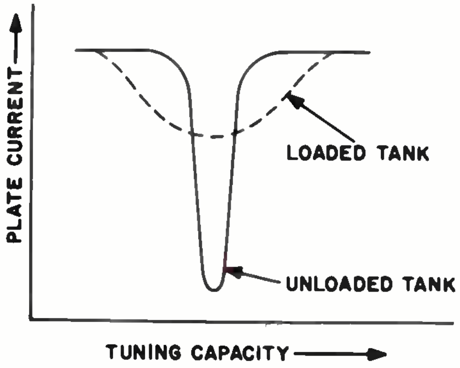


Fig. 38. How plate current dips as tank capacitor is tuned through resonance; the unbroken line shows the sharp dip that occurs if the tank is not loaded; the dashed line shows the broad dip that occurs if the tank is loaded.

The grid current meter will indicate maximum at resonance. Retune the grid tank capacitor, and increase the excitation until the grid draws the rated current.

Increase the loading in the plate tank circuit until any increase in loading causes the current through the antenna meter to drop. Increase the loading in steps. Check the plate circuit tuning for resonance each time you increase the load. Now apply the plate voltage and adjust it to the rated value.

Retune the plate tank to resonance, and then advance the loading until the tube draws the rated plate current. The minimum plate current point will not be as sharp because the tuned circuit is now loaded and more power is being fed into the load circuit. The loaded plate current tuning curve is shown by dotted lines in Fig. 38. Adjust the grid tank and excitation until the rated grid current is drawn.

Make final fine adjustments to the plate tuning and antenna loading. Be certain all meters show the recommended values for proper operation of the stage.

The output is indicated by the current readings on the rf antenna current meter. As the stage is resonated and the loading is increased, the antenna current increases, indicating power is being delivered to the antenna. The antenna meter is just as important as the plate ammeter when tuning. If the output current does not increase when the plate current increases, the plate circuit is not tuned to resonance or is overloaded. Reduce the coupling and retune the plate tank.

Parasitics. It is interesting to note that the wavemeter is also useful in detecting the presence of parasitics in the operating amplifier. As you know, these oscillations take place at a frequency far removed from the operating frequency. The most practical way to locate the oscillations is to reduce the bias of the stage so that the tube is no longer operated beyond plate-current cutoff. Then reduce the plate voltage so that the maximum plate dissipation of the tube is not exceeded. Disconnect the output and remove the drive from the stage. These changes make the circuit most favorable for the generation of parasitic oscillations.

With the wavemeter inductively coupled to the circuit suspected of oscillating, the wavemeter tuning knob is varied over its range. A meter deflection not only indicates parasitic oscillation, but the frequency may be approximately determined by the position of the tuning knob. Knowing the frequency at which parasitics are occurring often provides a clue to their origin.

THE TRANSISTOR STAGE

The transistor power amplifier, although used to some extent in low-level fixed station and broadcast transmitters, finds its widest application in low-powered mobile transmitting equipment. Since these units are operated largely by non-technical people working under less than ideal conditions, the emphasis in their design is on simplicity and reliability. Because of this emphasis, adjustment procedures for transistor class C amplifiers are usually simple and straightforward. The complete transmitter alignment of many of these units consists in its entirety of peaking the indication on a power output measuring device with as few as two transmitter adjustments.

Even in the more elaborate transmitters you'll seldom find more than one meter built into the equipment. This single meter is switched into the various points in the circuit where current or voltage is to be measured. Sometimes, all the monitoring points in the circuit are connected to a multipin jack on the transmitter chassis. When transmitter adjustments are to be made, an external meter equipped with a selector switch is plugged into this jack for monitoring.

Fig. 39 shows a parallel-connected output stage such as might be found in one of the higher powered transistor transmitters. We have shown separate meters at the various monitoring points for clarity. Before applying power to the amplifier, L_1 and L_3 should be adjusted for minimum drive to the transistors (adjusted for maximum inductance). With this accomplished, apply power and adjust the collector circuit of Q_1 to resonance. This is done by adjusting L_2 for a dip on M_1.

In like manner, adjust the collector circuit of Q_2 to resonance using L_4 and M_2. Next adjust the coupling to the load using C_1 to obtain the rated load current as measured on M_3. Finally, adjust the base drive to the transistors using L_1 and L_3 to obtain equal collector currents at the rated value. This completes the preliminary adjustment of the stage. Since there is some interaction between the various adjustments, recheck the setting of L_2, L_4, and C_1. At all times maintain the collector currents at or below the rated value by adjusting L_1 and L_3.

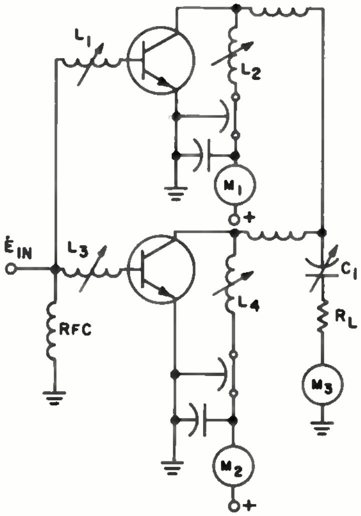


Fig. 39. Parallel-connected transistor stage.

In conclusion, the adjustments we've discussed in this section should not be considered as a procedure to be memorized and followed in any specific case. They are presented here to illustrate the basic approach to power amplifier adjustment. Before attempting any adjustment to a power amplifier, carefully consult and follow the manufacturer's literature. In making the adjustments, both the procedure and the sequence in which the steps are performed are of the greatest importance. An expensive tube or transistor may be destroyed as a result of any adjustments performed without complete knowledge of the correct procedure.

SELF-TEST QUESTIONS

(ah) How may a vacuum tube stage be checked for proper neutralization using the grid current meter as an indicator?

(ai) Why must B+ first be removed from a stage before checking the plate tank for the presence of rf?

(aj) What are some indications of a regenerative amplifier?

(ak) What tuning defect is indicated if the antenna current does not increase with an increase in plate current?

(al) Why is the drive to the transistor amplifier in Fig. 39 adjusted for minimum before collector power is applied.

Answers to Self-Test Questions

(a) Because output current flows in the amplifier only during the relatively brief conducting period.

(b) Both the bias level and the amplitude of the driving signal affect the operating angle.

(c) No. Sometimes, high power gain in an amplifier, obtained with a matched load, must be sacrificed for greater power output.

(d) The value of L and C would both have to be changed. L would be increased and C decreased.

(e) The loaded Q would decrease. The unloaded Q would be unaffected. The efficiency of the tank would increase.

(f) If the loaded Q decreases, the reflected resistance in the tank must have increased. The increased reistance in the tank causes tank impedance to decrease.

(g) By offering a high impedance only at the resonant frequency.

(h) By decreasing the spacing between the coils.

(i) Since the power supply, the tank, and the stage are in series, the amplifier is series-fed.

(j) The output connection to the tank could be tapped down on the tank coil, as is shown in Fig. 9C. This causes the internal resistance of the stage to appear to the tank as a higher value. This higher resistance seen by the tank reflects a higher resistance into the tank which increases the loaded Q.

(k) An antenna usually loads a power amplifier more heavily than the input circuit to another class C amplifier.

(l) If the drive to the stage is lost, no bias will be developed, allowing the tubes to conduct heavily. This heavy conduction could damage the tube.

(m) Through the plate-to-grid capacitance.

(n) Plate neutralization is effective over a range of frequencies, whereas the blocking capacitor and coil arrangement is effective only at one frequency.

(o) 180°. The signal fed back through a neutralizing circuit will always be 180° out-of-phase with the signal fed back through the grid to plate capacitance.

(p) The radio frequency choke.

(q) Parasitic oscillations in the amplifier.

(r) Their higher power gain and reduced grid-to-plate capacitance.

(s) Their higher power gain. Even a very small amount of feedback may cause the tetrode to oscillate.

(t) The value of L would be lower and the value of C higher. This would provide the lower value of tank impedance necessary for the parallel connected tubes.

(u) By connecting the supply voltages to the midpoints of the tank coils.

(v) The doubler. In general, the greater the frequency multiplication in a stage, the lower the power output.

(w) Since the output frequency is different from the input frequency, any signal fed back would not add to the input signal.

(x) The common emitter.

(y) The transistor stops conducting.

(z) Not always. A zero-biased transistor is already several tenths of a volt below collector current cutoff.

(aa) The low input impedance of the amplifier.

(ab) Because of the expense of the transformer required to drive a push-pull stage.

(ac) RF choke losses are eliminated and the transistors are electrically independent.

(ad) Because they have a very low lead inductance.

(ae) The collector base capacitance varies over the period of an operating cycle. Thus a varying amount of signal is fed back to the input.

(af) Low-frequency parasitics. The power gain of a transistor increases rapidly as frequency decreases. For this reason, a transistor amplifier is most susceptible to low-frequency parasitic oscillations.

(ag) Because of their physical construction, feed-thru capacitors cannot be manufactured with high values of capacitance. Proper bypass at low parasitic frequencies requires a large capacitance, so another type must be connected in parallel with the feed-thru.

(ah) With plate voltage removed, a dip in grid current when the plate tank is tuned through resonance indicates the need for neutralization.

(ai) With the B+ on the stage, rf in the tank circuit is a normal indication.

(aj) Changes in plate tuning affect grid tuning. Also, oscillations occur with reduced loading or slight changes in operating voltages.

(ak) The plate tank is not tuned to resonance or is too heavily loaded.

(al) To prevent possible excessive collector current flow due to the low impedance offered by the detuned output circuit.

NOTES

Lesson Questions

Be sure to number your Answer Sheet C205.

Place your Student Number on every Answer Sheet.

Most students want to know their grades as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time, or you may run out of lessons before new ones can reach you.

1. What is the primary purpose of a buffer stage?

2. What is the efficiency of a transmitter output stage if the plate supply voltage is 2000 volts, the plate current is 330 ma, and the measured power output of the stage is 500 watts?

3. What is the probable cause of trouble if the plate current of a class C stage using grid-leak bias alone rises to a very high value and the grid and output currents decrease?

4. Why is neutralization necessary in a triode amplifier?

5. Why are transistor rf amplifiers more susceptible to low-frequency parasitics than to those at higher frequencies?

6. Why does a screen-grid tube usually not require neutralization?

7. (A) If the master oscillator in a transmitter using a single doubler stage operates at 7.6 MHz, what is the transmitter output frequency?
   (B) If a transmitter output frequency of 26.4 MHz is obtained by using a single tripler stage, what is the frequency of the master oscillator?

8. What is the purpose of a Faraday screen?

9. What precaution should be taken when tuning the output of a frequency multiplier stage?

10. In adjusting a class C transmitter stage, what direction (upscale or downscale) would you expect the pointers on the following dc current meters to deflect to indicate resonance: (A) the plate current meter; (B) the grid current meter?

THE VALUE OF KNOWLEDGE

Knowledge comes in mighty handy in the practical affairs of everyday life. For instance, it increases the value of your daily work and thereby increases your earning power. It brings you the respect of others. It enables you to understand the complex events of modern life, so you can get along better with other people. Thus by bringing skill and power and understanding, knowledge gives you one essential requirement for true happiness.

But what knowledge should you look for? The first choice naturally goes to knowledge in the field of your greatest interest–electronics. Become just a little better informed than those you will work with, and your success will be assured.

It pays to know–but it pays even more to know how to use what you know. You must be able to make your knowledge of value to others, to the rest of the world, in order to get cash for knowledge.

The NRI Course gives you knowledge, and in addition shows you how to use what you learn. Master thoroughly each part of your Course, and you'll soon be getting cash for your knowledge.

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ACHIEVEMENT THROUGH ELECTRONICS

OSCILLATORS FOR COMMUNICATIONS EQUIPMENT

C206

NATIONAL RADIO INSTITUTE • WASHINGTON, D. C.

OSCILLATORS FOR COMMUNICATIONS EQUIPMENT

C206

STUDY SCHEDULE

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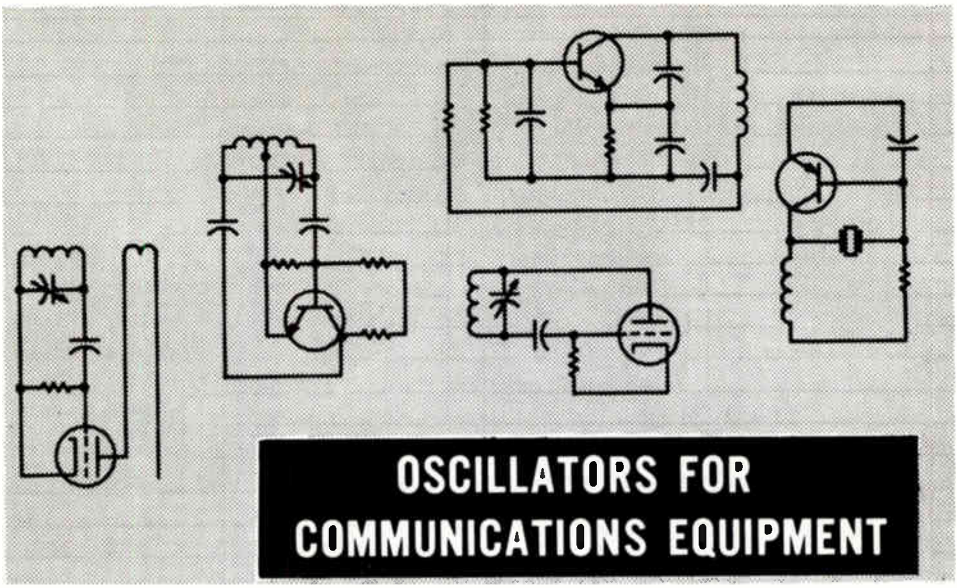

OSCILLATORS FOR COMMUNICATIONS EQUIPMENT

One of the most important circuits in electronics is the oscillator. If it were not for the oscillator, radio and television and many industrial electronics applications would not be possible. An oscillator is an amplifier which generates an ac signal. The frequency of the signal is determined by the value of the components in the oscillator circuit.

In this lesson you will begin with a study of the basic oscillator circuit. You will learn the characteristics of an oscillator and how the basic oscillator works. Then, you will study applications of the oscillator, learning the details of operation of various oscillator circuits. From there you will go into methods of controlling oscillator frequency. The lesson will conclude with a brief description of nonsinusoidal oscillators.

There are many different types of oscillator circuits. For convenience in studying them, we will divide them into two types: L-C oscillators and R-C oscillators. L-C oscillators are oscillators in which inductance and capacitance are used in the frequency-determining network. R-C oscillators are oscillators in which resistance and capacitance are used in the frequency-determining network. Both types of oscillators work on the same general principle, that of feeding some of the signal from the output circuit back into the input circuit. This feedback signal enables the oscillator to go on generating its own signal. The amount of signal that must be fed back into the input depends upon a number of things, but in general it must be enough to overcome the losses in the input circuit of the oscillator.

Perhaps one of the most important considerations in an oscillator circuit is how the energy is fed from the output circuit back into the input circuit. Although it is important to feed enough signal back into the input circuit, it is even more important for the signal fed from the output back into the input to be of the correct phase. If the phase of the feedback signal is not correct, instead of aiding the input signal, it will oppose it, and the oscillator will not oscillate.

Sometimes an oscillator is considered

as a converter circuit. In other words, it converts dc into ac. The dc is supplied by the power supply to the tube or transistor used in the oscillator circuit, which changes this dc energy to ac energy.

Oscillators are the only practical means of generating high-frequency radio waves. In the early days of radio, before practical oscillators were developed, rf signals were generated by means of high-frequency generators called alternators. However, there is a limit to how high a frequency a rotating machine such as an alternator can develop, and hence most radio transmission was carried out on very low frequencies.

The most important part of the oscillator is the resonant circuit, so before we begin let's review it. In a previous lesson, you learned that the resonant tank in a tuned amplifier biased class C could be made to store energy and to deliver that energy during periods when the tube or transistor was cut off. Oscillators function similarly to class C rf amplifiers in that the tank circuit must continue to supply an output once the input signal is removed.

One characteristic of a resonant circuit that we have not discussed is its ability to produce a damped wave when it is shock-excited. We will now see what we mean by a damped wave and see how it is produced by a resonant circuit.

DAMPED WAVES

Consider the circuit shown in Fig. 1. A coil and capacitor are connected in parallel and connected to a battery through a switch. For our discussion we must assume that the switch can be opened and closed instantaneously. Now let's see what happens when we close the switch for an instant.

At the instant the switch is closed, electrons flow from the negative terminal of the battery into side A of the capacitor. At the same instant, electrons will flow out of side B of the capacitor to the positive terminal of the battery. If the resistance in the circuit, which includes the battery resistance, is very low, the capacitor can charge up almost instantly to a voltage equal to the battery voltage. Thus, terminal A of the capacitor will be negative and terminal B will be positive.

At the same time, when the switch is closed, there will be some tendency for current to flow through the coil from terminal C to terminal D. However, you will remember that one of the characteristics of a coil or inductance is that it opposes any rapid change in the current flowing through it. The instant before the switch is closed, the current flowing through the coil is zero. The coil would like to keep it that way. When the switch is closed, the inductance of the coil tries to prevent a current from building up in the coil. Actually, there will be some small current flowing through the coil from terminal C to terminal D, but if the switch is closed only for an instant, the current will not be able to build up appreciably. Therefore, at the instant the switch is opened again we have the capacitor charged, as shown in Fig. 2A,

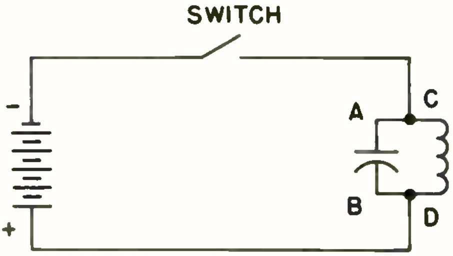

Fig. 1. A simple method of producing a damped wave.

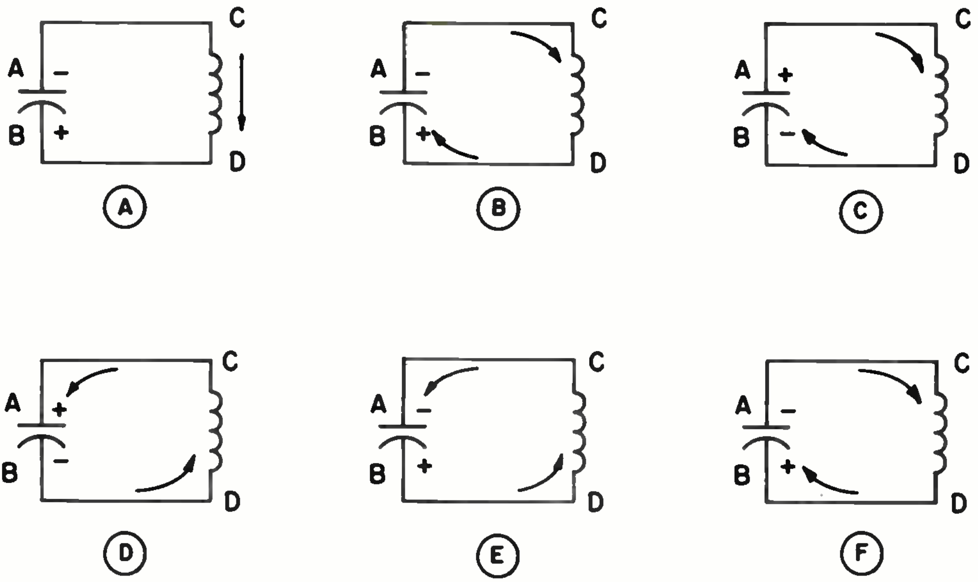

Fig. 2. How oscillation takes place in a resonant circuit.

and a small current flowing through the coil as indicated.

When the switch is opened and we have the situation shown in Fig. 2A, we have a capacitor that is charged, and immediately starts to discharge. As a result, a current flow will be set up in the circuit as shown in Fig. 2B. Now remember that a coil opposes a change in the current flowing through it. Therefore the capacitor cannot discharge instantly through the coil, but rather must build up a current in the coil which will build up a magnetic field about the coil. Eventually, the capacitor will build up a current flow in the coil and enough electrons will leave plate A to get to plate B to discharge the capacitor.

The discharge of the capacitor removes the voltage that caused current to flow through the coil. The magnetic field around the coil now collapses. The collapsing field generates an emf in the coil, which tends to keep the current flowing in the same direction as before. This continued current causes electrons to flow onto plate B of the capacitor, giving the capacitor a charge opposite to what it had at the start. This condition is shown in Fig. 2C.

After the field around the coil has collapsed, there is no emf to hold the charge on the capacitor. The capacitor now begins to discharge back through the coil as shown in Fig. 2D. The flow of current caused by the discharge of the capacitor builds up a magnetic field around the coil until the capacitor is fully discharged; the magnetic field collapses and keeps the current flowing. This current flow charges the capacitor with the same polarity it had at the instant the switch was opened. This is shown in Fig. 2E.

Again, the current will eventually drop to zero, and then the capacitor will once again begin to discharge through the coil in the opposite direction, this time with electrons flowing from plate A to plate B as shown in Fig. 2F.

Notice that in Fig. 2F we have the same situation as we had in Fig. 2B. In other words, we have gone through a complete cycle of events. The capacitor was charged with one polarity. This produced a current flow through the coil, which eventually charged the capacitor with the opposite polarity. The capacitor then began to discharge through the coil in the opposite direction, which built up a charge on it having the same polarity as the original charge placed on the capacitor. Once again this charge on the capacitor began the cycle of events all over again by attempting to discharge through the coil.

You might think that this oscillation, or backward and forward flow of current through the coil to charge and discharge the capacitor would continue indefinitely. Indeed, if we had a perfect coil and a perfect capacitor, once the oscillation was started, it would continue indefinitely. However, there is no such thing as a perfect coil or a perfect capacitor. There will be some losses in both parts, so instead of having an oscillation which continues indefinitely, we will have what is called a damped wave. The damped wave of voltage across the capacitor is shown in Fig. 3.

The important thing to notice in this damped wave is that the amplitude of each cycle is just a little bit less than the amplitude of the preceding cycle. In other words, the wave is slowly dying out because of losses in the resonant circuit. The lower the losses in the circuit, the greater the number of cycles that will occur before the wave disappears. On the other hand, the higher the losses in the circuit, the fewer the number of cycles.

If we could find some way of closing the switch in Fig. 1 for just an instant when plate A of the capacitor reaches its maximum negative charge, we could supply a small amount of energy to the resonant circuit to make up for losses in the circuit. If we continue to supply this small amount of energy once each cycle, then the resonant circuit will continue to oscillate indefinitely, and we could use it as a source of ac power. This is what an oscillator does, it supplies a pulse of energy at the correct time to make up for losses in the resonant circuit. We'll see how this is done later, but let's learn more about resonant circuits first.

FACTORS AFFECTING RESONANT CIRCUITS

There are several additional important things we should know about resonant circuits. For example, we should know the frequency at which oscillation takes place in a resonant circuit. We should also know what factors affect the loss of energy from cycle to cycle, in other words, how rapidly the wave train will die out.

Another term that we frequently encounter when dealing with resonant circuits is "period". We will now learn something about these factors.

Frequency. The frequency at which a resonant circuit oscillates will depend upon the inductance and capacitance in the circuit. We already know that resonance occurs when the inductive reactance of the coil is exactly equal to and

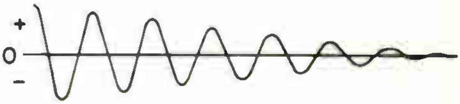

Fig. 3. Voltage across the capacitor.

canceled by the capacitive reactance of the capacitor. In other words, at resonance:

$$X_L = X_C$$

We know that the inductive reactance of a coil, X_L, is given by the formula:

$$X_L = 6.28 \times f \times L$$

and the capacitive reactance of a capacitor is given by the formula:

$$X_C = \frac{1}{6.28 \times f \times C}$$

Now, since resonance occurs when $X_L = X_C$, let's substitute the values for X_L and X_C and we will get:

$$X_L = X_C$$

$$6.28 \times f \times L = \frac{1}{6.28 \times f \times C}$$

and this can be manipulated to give us:

$$f^2 = \frac{1}{6.28^2 \times L \times C}$$

and now if we take the square root of both sides of the equation we get:

$$f = \frac{1}{6.28 \times \sqrt{L \times C}}$$

For convenience in expressing formulas of this type, the times sign is usually omitted, and in place of 6.28, the term 2π is often used, so you will usually see the formula for the frequency at which a resonant circuit will oscillate expressed as:

$$f = \frac{1}{2\pi \sqrt{LC}}$$

You should remember this formula because it is very important; but even more important, remember what the formula tells you. The formula says that the frequency of a resonant circuit varies inversely as the square root of the L-C product. Now remember as we mentioned before, when one factor varies directly with another, making one bigger makes the other bigger, and when two things vary inversely then we have the opposite situation; making one bigger makes the other smaller. Here we have a situation where the frequency varies inversely as the square root of the L-C product. This means that increasing the size of either L or C will reduce the frequency at which the resonant circuit oscillates, and reducing the size of either L or C will increase the frequency at which the resonant circuit oscillates. We can express this simply by saying: *Larger L or C, lower frequency; smaller L or C, higher frequency.*

In using this formula, the frequency of oscillation will be given in cycles per second and the value of L and C used must be in henrys and farads respectively.

Period. The period of a resonant circuit is the time it takes the resonant circuit to go through one complete oscillation. Thus, if we have a circuit that is resonant at a frequency of 1000 cycles per second, its period would be 1/1000 of a second, and if we have a resonant circuit that is resonant at a frequency of 1,000,000 cycles per second, the period would be 1/1,000,000 of a second.

The period of a resonant circuit is given by the formula:

$$P = \frac{1}{f}$$

where P represents the period of the resonant circuit in seconds and f the frequency in cycles per second.

Since in electronics we are usually dealing with comparatively high frequencies, it follows that the period of most resonant circuits will be only a very small fraction of a second. As a matter of fact, the period of many resonant circuits will be only a small fraction of a millionth of a second. Therefore, to simplify things, the microsecond is frequently used in electronics work as a unit of time. A microsecond is 1/1,000,000 (one millionth) of a second. Thus if a resonant circuit has a period of 5/1,000,000 (five millionths) of a second we can say that its period is 5 microseconds, or if another resonant circuit has a period of 1/10,000,000 (one ten millionth) of a second, we can say this period is one-tenth of a microsecond.

In order to show the cycle-time relationship, the frequency of a circuit is measured in units called HERTZ. One Hertz being equivalent to one complete cycle in one second, 1,000 cycles in one second would then be 1,000 Hertz (Hz) or one kilohertz (kHz). 1,000,000 cycles in one second would be one megahertz (MHz). These terms are replacing the older terms of kilocycles (kc) and megacycles (mc) still used in many publications.

The Q Factor. The number of cycles that will occur when a resonant circuit is shock-excited depends almost directly upon the Q of the coil. The higher the Q, the more cycles will occur.

The Q of a coil tells us essentially how good a coil we have. A coil that has a high Q has a high inductive reactance compared to the resistance of the coil. A coil with a low Q has high resistance compared with the inductive reactance.

The Q of a coil is expressed by the formula:

$$Q = \frac{X_L}{R}$$

and we can express X_L as equal to:

$$6.28 \times f \times L$$

and substituting this in the formula for the Q of a coil we get:

$$Q = \frac{6.28 \times f \times L}{R}$$

If we examine this formula, we see that the Q varies directly as the frequency and inductance and inversely as the resistance. Therefore, you might think that increasing the frequency of the resonant circuit by using a smaller capacitor in conjunction with the coil will result in a higher Q. This will often happen, but the increase in Q is not as great as might be expected, because the resistance of the coil is the ac resistance rather than the dc resistance. The ac resistance of a coil actually represents ac losses in the coil and this varies directly as frequency varies. Therefore, increasing the frequency of the resonant circuit increases the inductive reactance of the coil, but at the same time it increases the losses so that the Q normally does not increase as fast as we might expect.

In a resonant circuit with a high Q coil there will be a large number of cycles in a damped wave train set up by shock-exciting the resonant circuit. In other words, the amplitude of one cycle will be very little less than the amplitude of the preceding cycle. However, if the Q of the coil is low, then the losses in the coil will be quite high so that the amplitude of each cycle will be substantially less than the amplitude of the preceding cycle. This means that the oscillation will be damped out quite rapidly and the number of cycles that occur when the circuit is shock-excited will be somewhat limited.

In most oscillator circuits a comparatively high Q coil is used. The reason for this is that if the coil has a high Q, then only a small amount of energy must be supplied by the tube or transistor in the oscillator circuit in order to sustain oscillation. On the other hand, if the coil has a low Q, the losses in the resonant circuit will be quite high, with the result that the tube or transistor used in the oscillator circuit must supply a comparatively large amount of energy in order to keep the oscillation going.

SELF-TEST QUESTIONS

(a) What type of feedback is used in oscillator circuits?
(b) If the inductance of an L-C circuit is increased, what happens to the frequency?
(c) If the Q of the resonant circuit is increased, what happens to the damped wave train?
(d) If the resonant frequency of an L-C circuit is 2000 kHz, what is the period of one cycle?

The Basic Oscillator

The function of the switch in Fig. 1 is to supply energy of the proper phase and at the proper time to sustain oscillations in the resonant circuit. At radio frequencies it would be impossible for a mechanical switch to do this. Therefore, we must use an electronic switch such as a vacuum tube or transistor.

THE ELECTRONIC SWITCH

In order to see how the vacuum tube can be used as an electronic switch, let's go back to the basic circuit we had in Fig. 1. We have repeated this circuit as Fig. 4A. It is exactly the same as Fig. 1 except we have simply indicated where the battery voltage is to be connected instead of actually showing the battery in the circuit. In practice, we could use either a battery or the dc output of a suitable power supply. If we can momentarily close the switch, we will charge the capacitor C_1 and produce oscillation in the parallel resonant circuit consisting of C_1 and L_1. However, this oscillation will die out after a number of cycles because of the losses in a resonant circuit, unless we can find some way of supplying additional energy to the resonant circuit to make up these losses. If we could close the switch at the right instant each cycle, we could recharge capacitor C_1 once each cycle and keep the oscillation going. However, if the resonant frequency of the circuit is several hundred Hertz or higher, it would be impossible to close the switch manually at the correct instant to keep the oscillation going. As a matter of fact, it would be difficult to do this mechanically except at a very low frequency.

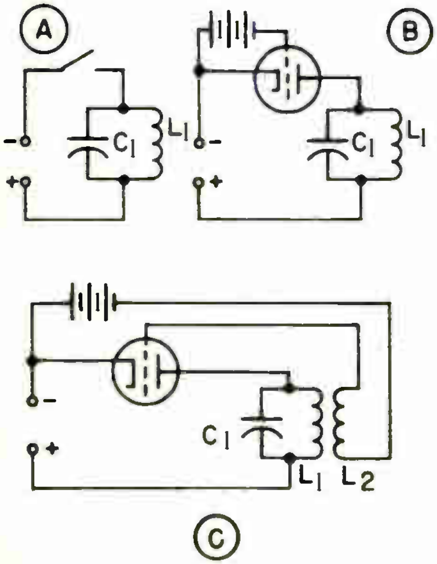

Fig. 4. Using a tube as an electronic switch to supply the losses in a resonant circuit.

In Fig. 4B, we have replaced the switch with a vacuum tube. The cathode of the vacuum tube is connected to the negative side of the power supply or battery, and the plate of the tube is connected to the resonant circuit. Between the cathode and the grid of the tube, we have connected a battery that will place a negative voltage on the grid of the tube. The battery voltage in the grid circuit is high enough to bias the tube beyond cutoff. Thus, with the circuit exactly as shown in Fig. 4B, the bias on the tube is so high that there will be no current flowing through the tube and hence no way to charge capacitor C_1 and start the resonant circuit oscillating. We have in effect the same situation as we have in Fig. 4A with the switch open.

Now let's look at the circuit shown in

Fig. 4C. Here we still have the tube connected in the circuit in exactly the same way except that we have added a coil, L_2, between the negative terminal of the grid battery and the grid of the tube. This coil is placed near L_1 so that it will be inductively coupled to L_1. Thus, .if there is any change in the magnetic field about L_1, the changing flux will induce a voltage in L_2.

Now let's consider what will happen if we momentarily short the plate and cathode of the tube together. If we do this, capacitor C_1 will be charged. As soon as we remove the short, C_1 will start to discharge through L_1 and in doing so will build up a magnetic field about L_1. The changing lines of flux will cut L_2 and induce a voltage in it. This voltage in L_2 will be in series with the battery voltage applied between the cathode and grid of the tube. If the end of L_2 that connects to the grid of the tube is negative, and the other end positive, then the voltage induced in L_2 will add to the grid bias, biasing the grid still further negative so that no current can flow from the cathode to the plate of the tube. However, if the voltage induced in L_2 has a polarity such that the end of L_2 that is connected to the grid is positive, and the other end is negative, then this voltage will oppose the battery bias voltage and reduce it so that the total grid bias will be reduced below the point where the plate current is cut off, and current can flow through the tube. Therefore, by connecting L_2 with the proper polarity, we can arrange the circuit so that when the plate side of capacitor C_1 reaches its negative peak, the tube will conduct, and a burst of electrons will flow through the tube, charging C_1 still further. Thus, any loss in the charge across C_1 due to losses in the resonant circuit will be made up for by the burst of electrons flowing through the tube.

In Fig. 5, we have shown a number of sine-wave cycles such as the oscillation that might occur in the L_1-C_1 resonant circuit. The shaded pulses represent the bursts of current flowing through the tube that will reinforce the oscillation and keep it going. Notice in Fig. 5 that the burst of current flowing through the tube occurs at the correct instant to aid the oscillation. Also, notice that the current burst occurs for only a small fraction of a cycle. The current does not flow through the tube during the entire cycle.

For several reasons the oscillator circuit shown in Fig. 4C is not a practical circuit. For one thing, the battery used to provide the negative bias on the grid is somewhat cumbersome. If we were using a power supply to furnish the voltage to operate this oscillator from a power line, we would not want to be bothered with a separate battery to supply the grid bias. Furthermore, with this type of arrangement, it would be possible to pick up such a high voltage pulse in L_2 that the tube would pass an extremely high current when it was driven in a positive direction. As the grid bias battery aged and the voltage from this battery dropped, an even higher current pulse would flow through the tube. As a matter of fact, the pulse might be so high that the tube could be damaged.

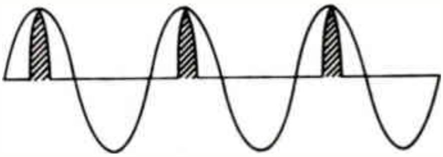

Fig. 5. The oscillator pulse is timed to occur at the peak of the oscillation in the tank circuit to reinforce the oscillation.

Both of these objections can be overcome by modifying the circuit as shown in Fig. 6. Let's look at Fig. 6A first. In Fig. 6A, you will see that we have replaced the battery in the grid circuit by a resistor, R_1, with capacitor C_2 connected across it. In other respects the circuit is identical to the circuit shown in Fig. 4C.

Let's see exactly how this circuit works. When voltage is first supplied to this circuit, there will be no grid bias on the tube. The tube starts to conduct and charges capacitor C_1. Electrons will flow into the side of this capacitor that connects to the plate of the tube and out of the other side. At the same instant, current will start to flow through L_1 and there will be a rapid change in the lines of flux about this coil. The changing magnetic lines will cut L_2, and induce a rather high voltage in it. Coil L_2 is connected so that the grid of the tube will be driven in a positive direction, which will result in a still further increase in current flowing from the cathode to the plate of the tube, which will charge C_1 still further.

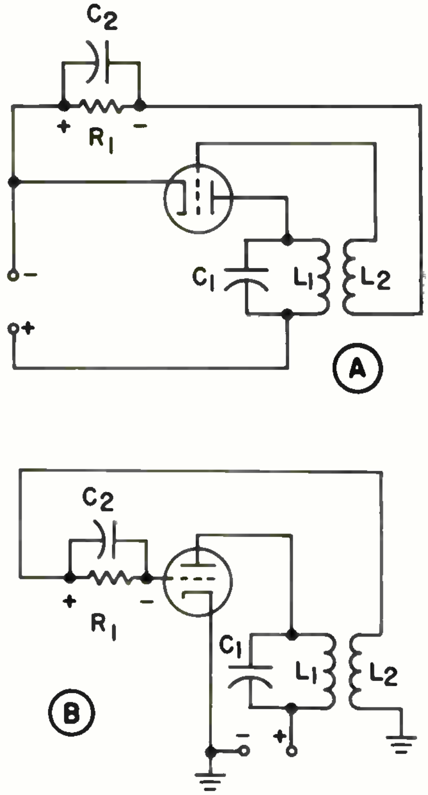

Fig. 6. A tuned-plate oscillator.

Since the grid of the tube will be driven in a positive direction, it too will attract electrons, and electrons will flow from the cathode of the tube to the grid, through L_2, and then through R_1 back to the cathode of the tube. In flowing through R_1, they will set up a voltage drop across it and charge capacitor C_2 with the polarity indicated on the diagram.

Eventually the rate at which the flux lines are cutting L_2 will decrease, so the voltage induced in coil L_2 will drop. The voltage across R_1 will cut off the flow of plate current in the tube. Capacitor C_2 starts to discharge through R_1 and keeps the grid of the tube at a high enough negative potential to keep it cut off. When this happens, we have opened the switch as in Fig. 1 and an oscillation starts in the tank circuit. The capacitor and coil begin exchanging energy back and forth. At the correct instant, once in each cycle, the grid of the tube will be driven positive by the voltage induced in L_2 by the changing flux from L_1 so that the tube will pass a burst of electrons to recharge C_1 and make up any energy lost in the tank circuit.

The oscillator we have been discussing is called a tuned-plate oscillator. In actual practice, the circuit is modified and you will usually see it like Fig. 6B. Notice that the position of the grid resistor and grid capacitor, R_1 and C_2, have been changed with reference to L_2. In other words, tracing from the grid of the tube, we come to the grid resistor and grid capacitor first and then through L_2 to ground. However, regardless of how the resistor and capacitor are connected in series with L_2, the action of the circuit is the same.

This type of oscillator has several disadvantages that can be eliminated by different circuitry. However, since it is a basic circuit and enables us to see exactly how the tube is acting as a switch, it is a good circuit to start our study of oscillators with.

SELF-REGULATION

The oscillator circuits shown in Fig. 6 are self-regulating. This means that they tend to control the flow of current through the tube themselves. For example, suppose the amplitude of the pulse picked up by L_2 should increase for any reason; if this happens, the pulse will drive the grid even more positive than normal. With a higher positive voltage on the grid, a greater number of electrons will be attracted to it. An increase in the number of electrons reaching the grid will mean that more electrons must flow through R_1. The voltage developed across R_1 depends upon two things: the size of the resistor and the number of electrons flowing through it. Therefore, if the number of electrons flowing through R_1 increases, the voltage developed across it will increase.

Notice the polarity of the voltage across R_1. The grid end of this resistor is negative, so this bias voltage tends to reduce the flow of current through the tube. Therefore, the increase in negative voltage across R_1 will subtract from the increase of positive voltage across L_2 so that the net drive voltage applied to the grid remains almost the same. Thus, even though something might cause the voltage developed in L_2 to increase, the tube will compensate for this change by developing an increased bias so that the burst of plate current flowing through the tube will remain essentially constant.

OSCILLATOR-AMPLIFIER

Up to this point, we have been considering the tube as a switch that closed at the proper instant to replenish the losses in the resonant circuit. We can also consider the tube as an amplifier that is amplifying part of its own output. For example, L_1 and L_2 in Fig. 6B are inductively coupled together. Part of the output produced across L_1 is coupled to L_2, where it is fed back into the input circuit. This signal fed into the input circuit is then amplified by the tube and fed to the resonant circuit L_1-C_1 in the output. The cycle then continues, with part of the output being coupled to L_2 and once again being fed back to the input. Thus, the oscillator can indeed be considered as an amplifier that feeds part of its own output signal back to the input, where it is amplified once again.

Of course, the signal fed back to the input must be of the proper phase to sustain oscillation. The signal must drive the grid in a positive direction when the plate current flowing through the tube should increase. Feedback of this type is called regenerative feedback. In some amplifiers a small amount of regenerative feedback is used to improve the gain of the amplifier. However, in an oscillator, enough regenerative feedback is used to start the stage oscillating, and to keep it oscillating.

OSCILLATOR FREQUENCY

You already know that the resonant frequency, f_0, of a circuit containing L and C is:

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

The resonant frequency is also often expressed in terms of resonant angular frequency, ω_0:

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

where $\omega_0 = 2\pi \times f_0$. This expression comes from the fact that there are 2π radians in 360°. A radian is an angular measurement equal to approximately 57°. Since there are 2π radians in 360°, a vector rotating at f_0 Hertz travels through $2\pi \times f_0$ radians per second.

You might at first expect an L-C oscillator to operate at exactly ω_0, the resonant frequency of the L-C circuit. However, there is always some resistance in the circuit that affects the oscillator frequency. Furthermore, the plate resistance of the tube affects the oscillator frequency so that the actual frequency of the oscillator, ω, is:

$$\omega = \omega_0\left(1 + \frac{R}{R_p}\right)$$

where ω_0 is the angular resonant frequency of the L-C circuit, R represents the resistance in the resonant circuit, and R_p is the plate resistance of the tube.

In most oscillator stages the value of R will be small, because the Q of the oscillator coil will be high. At the same time, the plate resistance of the tube will be reasonably high so the term R/R_p will be small and ω will be almost equal to ω_0. However, the fact that R and R_p do enter into the frequency means that if either of these values change, the oscillator frequency will change. Thus, oscillator stability depends not only on keeping the values of L and C in the resonant circuit constant, but also the value of R and R_p must be kept constant.

OSCILLATOR STABILITY

One of the most important considerations in oscillator circuits is the stability of the oscillator – in other words, how stable the oscillator frequency is. The output frequency of a radio transmitter is controlled by the oscillator, and if the oscillator frequency does not remain constant, the transmitter output frequency will not be constant.

We have already pointed out that the oscillator frequency depends not only upon the inductance and capacitance in the resonant circuit, but also on other factors such as the resistance of the oscillator coil and the plate resistance of the oscillator tube. Now, let us consider each of these factors to see exactly what effect each has on the oscillator frequency.

Tank Inductance and Capacitance. The inductance in the oscillator tank circuit is made up of the inductance of the oscillator coil, plus any stray inductance in the circuit. The capacitance in the oscillator tank circuit is made up of the capacity connected across the oscillator coil plus any tube capacity that may be in parallel with the coil and capacitor, and the distributed wiring capacity in the circuit. The inductance in the circuit consists of the oscillator coil, the inductance of the leads connecting the coil to the tube and other parts in the circuit, and any inductance that other parts in the circuit may have. The capacity in the circuit consists of the capacity of the variable capacitor across the oscillator coil, the input capacitance of the tube, the stray wiring capacity in the circuit, plus any stray capacity the coil may have. This total inductance plus this total capacity are the major factors that determine the oscillator frequency.

When an oscillator is first turned on, the values of the inductance and capacitance in the tank circuit will usually change as the tube and other parts in the circuit heat. Therefore, the oscillator stability is usually measured in terms of the oscillator's ability to maintain a constant frequency after enough time has been allowed for the tube and parts to reach normal operating temperature. It is common practice in some transmitters to leave the oscillator on at all times to avoid any frequency drift during the warmup period. In some transmitters, the oscillator coil and capacitor are placed in an oven that is kept at a constant temperature by a thermostatically controlled heater to minimize changes in inductance and capacity due to temperature changes. In some oscillators, special temperature compensating capacitors are connected across the oscillator tank circuit to minimize frequency drift due to temperature changes. These capacitors usually have a negative temperature coefficient. This means that their capacity decreases as the temperature increases. By using a capacitor of this type with the correct temperature coefficient, it is possible to compensate for any increase in inductance or capacitance in other parts in the circuit as the temperature increases.

Changing a tube in the oscillator circuit can result in a change in oscillator frequency. The input capacity of the tube used in the oscillator circuit makes up part of the oscillator tank circuit. The input capacity of different tubes of the same type may vary appreciably, so putting a new tube in this or any other oscillator circuit may change the tank circuit capacitance, and hence the frequency. Therefore, if you replace the oscillator tube in a transmitter you should check the output frequency.

Tank Losses. Earlier we pointed out that the angular resonant frequency, ω_o, of the oscillator tank circuit is given by:

$$\omega_o = \frac{1}{\sqrt{LC}}$$

and at the same time, the actual frequency at which the oscillator oscillates is given by:

$$\omega = \omega_o\left(1 + \frac{R}{R_p}\right)$$

where R is the resistance in the tank circuit and R_p the plate resistance of the tube.

The term R represents the ac resistance of the tank circuit, and as such represents all the losses in the tank circuit. Thus, this term includes such factors as coil resistance and losses from the oscillator circuit due to loading of the circuit. Therefore, any change in the oscillator coil resistance will result in a change in oscillator frequency. Similarly, a change in the loading on the oscillator will result in a change in oscillator frequency. Thus, for maximum stability, the oscillator should be lightly loaded and the load on the oscillator must remain constant.

The Plate Resistance. Since the plate resistance of the tube enters into the frequency of the oscillator, any change in plate resistance will produce a change in the oscillator frequency. The plate resistance of the tube will change if either the plate or grid voltage is changed in the case of a triode, and if the grid or screen voltage (and to some extent the plate voltage) is changed in the case of a pentode. Thus, it is important that the voltages supplying the oscillator be kept constant. These voltages must also be free of hum, which actually is a changing voltage superimposed on the dc supply voltage, because the hum voltage could produce a constantly changing plate resistance which will result in a frequency-modulated signal being generated by the oscillator.

Changes in loading on the oscillator may affect the bias developed on the grid of the tube. When this happens, the grid voltage will change, causing the plate resistance and hence the frequency to shift.

Looking at the expression for the oscillator angular frequency, we see that the frequency is equal to the angular frequency of the tank circuit times one plus a fraction. Thus, the oscillator frequency will be higher than the resonant frequency of the tank circuit. Also, if the term R/R_p is small, which it usually is, the oscillator frequency will differ from the tank frequency by only a small percentage. However, at high frequencies, this small percentage or fraction can represent a great enough frequency change to cause concern. For example, if the resonant frequency of a tank circuit is 10 MHz and the value of R/R_p is only .01, .01 X 10,000 kHz represents 100 kHz so the oscillator frequency would be 10,101 kHz, or 10.1 MHz. If the value of R_p changed because of changing voltages on the tube, the oscillator might drift 50 kHz or more above or below this frequency.

TRANSISTOR OSCILLATORS

Of the three basic transistor configurations, the common emitter is the most frequently used in rf oscillator circuits. There are several reasons for this. The power, current and voltage gains of the common-emitter configuration are all greater than one, and the highest possible power gain can be had. Also in the common-emitter circuit, moderate input and output impedances make less power necessary for feedback. In the common-base configuration, low input and high output impedances inherent in the circuit cause a mismatch in the feedback circuit, producing greater losses and requiring more feedback. The current gain in the common-base circuit is less than one, even though voltage and power gains are greater than unity. A somewhat similar condition exists in a common collector circuit where high input and moderate output impedances exist. Voltage gain is less than unity, but current and power gains are greater than one.

Transistor oscillators may be designed to operate class A, B or C depending on the desired efficiency. Since rf oscillators are also amplifiers, bias supply and temperature stabilization are similar to rf amplifiers discussed in a previous lesson.

A combined voltage divider and feedback type biasing arrangement is often used because it helps produce oscillation and at the same time establishes a stable dc bias point. Emitter biasing with a bypass capacitor is also used, the operation being similar to grid leak biasing. Usually the amplitude is regulated by driving the transistor into saturation or by using special diode limiting circuits. Either shunt or series type collector feed may be used, the shunt type being preferred for greater output efficiency.

Frequency stability of the transistor oscillator is equivalent to, and sometimes greater than the electron tube oscillator. The use of lower voltages, currents and power, permits construction of better tank circuits. In particular, the low power used with transistors aids in stability due to the decrease in heat. One major disadvantage of transistors is their critical operating point. A slight bias change can cause a large shift in frequency.

The collector-to-emitter capacitance of the transistor also affects frequency stability. This internal capacitance will vary with changes in collector or emitter voltages and with temperature. In high frequency oscillators it is sometimes necessary to place a swamping capacitor across the collector to emitter leads. The total capacitance of the two in parallel results in a circuit which is less sensitive to voltage changes. The added capacitor may be a part of the tuned circuit.

Partial compensation of voltage changes may be obtained by use of a common supply. Since an increase in collector voltage tends to increase oscillator frequency and an increase in emitter voltage decreases oscillator frequency, the use of a common bias source for both the collector and emitter helps stabilize the frequency. By using a common bias source, a change in one is somewhat counteracted by the change in the other.

The three basic transistor configurations used for oscillators are shown in Fig. 7. Bias and feed arrangements are omitted for simplification. Although any of the three basic transistor configurations can be used, generally only two, the common-emitter and common-base, are used in actual practice. The common-emitter configuration offers the advantages of easily matched input and output impedances and its close parallel to the electron tube.

The major advantage of the common-base circuit is that at high frequencies collector-emitter capacitance helps feedback an in-phase voltage independently of tickler coil L_1, and oscillation is more easily obtained. In the common-emitter circuit, this capacitance feeds back an out-of-phase voltage which requires additional feedback from the tickler coil to

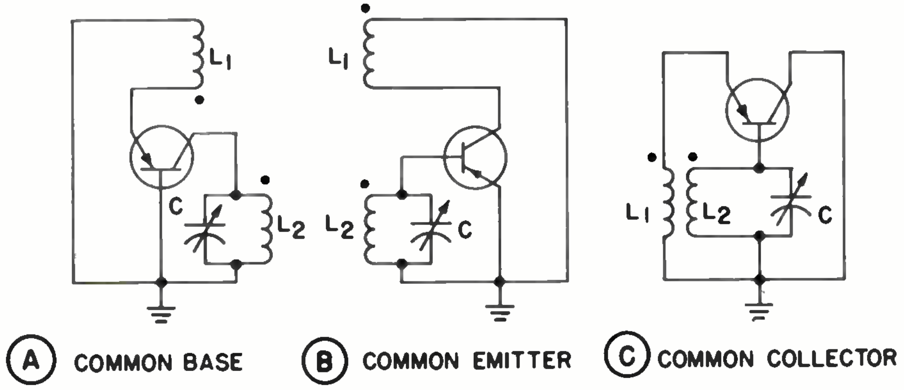

Fig. 7. Tickler coil oscillators.

overcome it. In both the common-base and common-emitter circuits, oscillation is easily sustained. This is the result of feedback provided by voltage induced through the mutual inductance of L_1 and L_2. In the common-collector circuit, the voltage gain is always less than unity, therefore feedback tends to be insufficient for stable oscillations at the lower frequencies. At the higher frequencies it is assisted by the collector-emitter capacitance. Sometimes, an external capacitor is added between the collector and emitter to give additional feedback.

Operation of the L-C circuit is similar to that of the electron tube circuit. As the oscillator is switched on, current flows through the transistor as determined by the biasing circuit. Initial current produces a feedback voltage between the collector and the emitter which is in-phase with the input circuit. As emitter current increases, collector current increases and additional feedback between L_1 and L_2 causes the emitter current to increase until saturation is reached. When saturation is reached, emitter current is no longer changing (increasing), and the induced feedback voltage is therefore reduced. At this time the collapsing field around the tank and tickler coils induce a reverse voltage into the emitter circuit which causes a decrease in the emitter current, thus causing a decreasing collector current. The decreasing current then induces a greater reverse voltage in the feedback loop driving the emitter current toward cutoff.

Although the emitter is cut off, a small reverse (leakage) current flows. This current has no effect on the operation of the circuit but it does represent a loss which lowers the efficiency. In this respect the transistor differs from the electron tube, which has zero current at cutoff.

The discharge of the tank capacitor through L_2 will cause the voltage applied to the emitter to rise from a reverse-bias to forward bias condition. Emitter and collector current start to increase and the cycle repeats itself.

The transistor oscillator circuit that most closely resembles the tuned-plate vacuum tube oscillator is the tuned-collector oscillator. This circuit is shown in Fig. 8.

Notice that in this circuit the resonant circuit consisting of C_1-L_1 is in the collector circuit of the transistor. L_2 is inductively coupled to L_1 so energy is fed from L_1 to L_2. The signal developed in L_2 is fed back to the base of the transistor.

In the operation of this oscillator, resistor R_1 and capacitor C_2 develop a bias voltage sufficient to cut off the transistor. The signal needed to overcome this cutoff bias is induced in L_2 and applied between the base and the emitter. Since this is a PNP transistor, the signal in L_2 must make the base negative and the emitter positive at the instant that a pulse of current is needed from the collector in order to sustain oscillation in the resonant circuit consisting of L_1 and C_1.

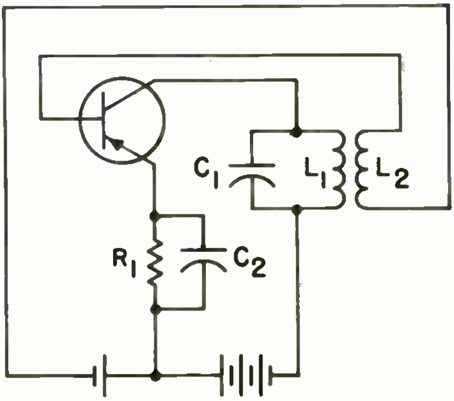

Fig. 8. A tuned-collector oscillator.

SELF-TEST QUESTIONS

(e) Describe the phase relationship between the plate current wave shape and the voltage wave shape developed across L_2 in Fig. 4C.

(f) What makes the oscillator in Fig. 6B self-regulating in regard to the amplitude of the grid signal?

(g) List three methods of reducing frequency drift due to changes in temperature in a resonant circuit.

(h) In high frequency transistor oscillators what is sometimes used to compensate for collector-to-emitter capacitance?

(i) In the oscillator circuit in Fig. 8, where is the bias developed and what component develops the signal that overcomes this bias?

Practical Oscillator Circuits

The oscillator circuits we have discussed up to this point weren't very practical. They were used to illustrate some of the basic characteristics of oscillators. Let us now look at some practical circuits actually found in communication equipment. These oscillators are grouped according to the type of resonant circuit used, inductance-capacitance (L-C) or resistance-capacitance (R-C).

L-C OSCILLATORS

The L-C oscillators can be placed into one of two classifications: those using inductive feedback and those using capacitive feedback. The inductive feedback oscillator uses inductive coupling to return a portion of the output back to the input. The capacitive feedback circuit uses capacitive coupling to accomplish this. Although there is some difference in the circuitry involved, both types are L-C oscillators, and the net result is essentially the same.

OSCILLATORS USING INDUCTIVE FEEDBACK

One of the most important and most widely used oscillators in electronics work is the Hartley oscillator. This oscillator uses inductive feedback. The resonant circuit is placed in the grid circuit of the tube or the base circuit of the transistor instead of in the output circuit as in the case of the tuned-plate and tuned-collector oscillators. However, before we look at the Hartley oscillator let's look at another oscillator which will help you understand how the Hartley oscillator works. Let's first look at the tuned-grid oscillator.

Tuned-Grid Oscillator. Two versions of the tuned-grid oscillator are shown in Fig. 9. The circuits are basically the same; the only electrical difference is in the connection of the grid resistor R_1. In the circuit shown in Fig. 9A, R_1 is connected directly across the grid capacitor C_2, whereas in the circuit shown in Fig. 9B, R_1 is connected between the grid and the cathode of the tube. The action of R_1 is the same in both cases; it provides a path for the electrons striking the grid of the tube to get back to ground or the cathode

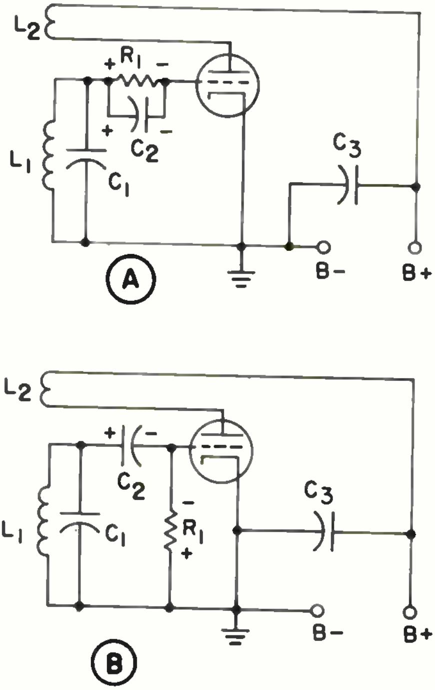

Fig. 9. Two versions of the tuned-grid oscillator.

of the tube. In the circuit of Fig. 9A, when C_2 discharges through R_1 to develop negative bias for the tube, there is no discharge through the tank circuit. In Fig. 9B, when C_2 discharges through R_1, the discharge current also flows through the tank circuit.

Actually, the biggest difference between this oscillator and the tuned-plate oscillator that you already studied is that the resonant circuit is in the grid circuit instead of the plate circuit. With this circuit, when the power is turned on, changes in plate current will set up a changing magnetic field about L_2. L_2 is inductively coupled to L_1 so the changing magnetic field about L_2 will induce a voltage in L_1. The induced voltage charges capacitor C_1, starting the oscillatory discharge in the tank circuit consisting of L_1-C_1. The voltage across C_1 becomes the grid voltage because the value of C_2 is large enough so that its reactance is so small at the frequency of oscillation, that the grid is, in effect, connected directly to C_1.

Now since the increasing plate current causes the end of C_1 that is connected to the grid through C_2 to swing in a positive direction, the grid of the tube is driven in a positive direction. Driving the grid positive produces two effects; it increases the plate current, causing C_1, and hence the grid, to be driven still further in a positive direction, and it causes grid current to flow, which charges C_2 with the polarity shown on the diagram.

Now if the plate current of the tube could keep on increasing indefinitely, the grid end of C_1 would be driven more and more positive. However, there is a limit to how high the plate current can become, because a balance will be reached between the positive voltage across C_1 and the negative voltage across C_2. When this happens, the plate current flowing through L_2 will no longer change. We will no longer have voltage induced in L_1, and C_1 will begin to discharge through L_1, setting up an oscillation in the L-C circuit. As soon as this happens, the positive voltage on the grid end of C_1 begins to disappear, and the plate current will be cut off by the negative voltage across C_2. The L-C circuit is now free to oscillate as though the tube were removed from the circuit. C_2 meanwhile starts to discharge through R_1, setting up the voltage drop across it as shown on the diagram. During the next half cycle when the voltage on the grid end of C_1 again becomes positive, it will drive the grid in a positive direction enough to let some plate current flow through the tube; this will result in a change in the field about L_2 which will induce a voltage in L_1 which drives the capacitor and the grid voltage still further in a positive direction.

The important point to remember about this oscillator is that the energy needed to sustain the oscillation in the tank circuit, consisting of L_1 and C_1, is inductively coupled to L_1 from L_2. This energy comes from the plate of the tube in the form of bursts of plate current which produce a changing magnetic field about L_2. These bursts of current are the result of the grid of the tube being driven positive by the voltage across C_1 swinging positive once each cycle.

The Hartley Oscillator. Two Hartley oscillators are shown in Fig. 10. The circuit shown in Fig. 10A uses a vacuum tube, whereas the one shown in Fig. 10B uses a transistor. Although the operation of the two circuits is so similar that if you understand one, you will understand the other, we will go through both circuits in considerable detail.

Notice the difference between the

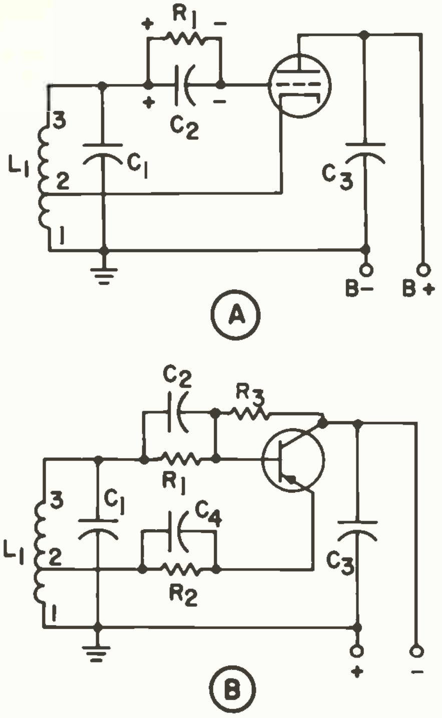

Fig. 10. Typical Hartley oscillators; a vacuum tube Hartley oscillator is shown at A, and a transistorized one at B.

Hartley oscillators and the tuned-grid oscillators. The tuned-grid oscillator has two coils, whereas the Hartley oscillator uses only a single tapped coil. In the circuit shown in Fig. 10A, the cathode of the tube is connected to the tap, and in the circuit shown in Fig. 10B, the emitter of the transistor is connected to the tap.

In the circuit shown in Fig. 10A, when the plate current starts to flow through the tube, current must flow through the lower half of the coil between terminals 1 and 2. Since the entire coil is wound on a single form, all the various turns of the coil are inductively coupled together. Therefore the increasing plate current flowing between terminals 1 and 2 will produce a changing magnetic field which will induce a voltage in the portion of the coil between terminals 2 and 3. This voltage will charge capacitor C_1 with the polarity such that the end of the capacitor that connects to the junction of C_2 and R_1 is positive. Again since the value of C_2 is chosen so that its reactance is practically zero at the oscillation frequency, the grid of the tube is in effect connected directly to C_1. This means that the increase in plate current will drive the grid of the tube in a positive direction, causing a still stronger burst of current through the coil. This in turn causes still higher induced voltage between terminals 2 and 3 which again charges capacitor C_1 still further. At the same time when the grid is driven positive, it will attract electrons, and C_2 will be charged with the polarity shown.

As in the tuned-grid oscillator, the point is eventually reached where there is a balance between the positive voltage applied to the grid by C_1 and the negative voltage applied to the grid across C_2 and R_1 so that there is no further increase in plate current. This means that the magnetic field produced by the current flowing between terminals 1 and 2 becomes constant and no further voltage will be induced in the coil. C_1 starts to discharge through the coil, and the oscillating cycle is started. Furthermore, the positive voltage on the end of C_1 that connects to the grid of the tube through C_2 disappears, and the tube stops conducting.

Again, the tube will be biased beyond cutoff by the discharge of C_2 through R_1. These electrons charge C_2 during the portion of the cycle when the grid is conducting. When grid current stops flowing, C_2 will discharge through R_1, setting up a voltage drop across it such that the grid end is negative. This voltage across R_1 maintains the bias on the grid of the oscillator tube.

In some cases you will see slight variations of the Hartley oscillator circuit. In some instances, R_1 may be connected between the grid and cathode or from the grid of the tube directly to ground. In another variation the cathode connects directly to ground, R_1 connects between the grid of the tube and ground, and then the plate of the tube connects directly back to terminal 1 of the oscillator coil. The B+ voltage is then applied to terminal 2 of the coil. This is simply a modification of the Hartley oscillator circuit; it works in exactly the same way as the Hartley oscillator shown in Fig. 10A.

In the circuit shown in Fig. 10B we have a PNP transistor. When holes begin to travel from the emitter to the collector, electrons will flow from the emitter through R_2 to terminal 2 on the coil. From terminal 2 they will flow through the coil to terminal 1 and back to the positive terminal of the battery. The electrons, in flowing through the coil from terminal 2 to terminal 1, will build up a field about this part of the coil. This field will be a changing field as the current builds up, and this will induce a voltage in the portion of the coil between terminals 2 and 3. This induced voltage will charge C_1 with the polarity such that the end connecting to terminal 3 of the coil is negative and the other end is positive. This negative voltage on one end of C_1 will be applied to the base of the transistor through capacitor C_2 because C_2 has a low reactance at the frequency of oscillation. The negative voltage on the base of the transistor will increase the forward bias across the emitter-base junction, causing an increase in the number of holes flowing from the emitter to the collector. This causes a still further increase in the electron movement from terminal 2 to terminal 1 of the coil, causing the base of the transistor to be driven still further in a negative direction.

In this circuit when the number ot holes flowing from the emitter to the collector increases, terminal 3 of the coil will be driven in a negative direction, and when the holes flowing from the emitter to the collector decrease, terminal 3 will be driven in a positive direction. Remember that in a PNP transistor, driving the base in a negative direction causes the holes moving through the transistor to increase, whereas driving it in a positive direction causes the number of holes flowing from the emitter to the collector to decrease. The burst of hole movement through the transistor causes the electron movement from terminal 2 to terminal 1 of coil L_1 to flow through the coil in burst, and this burst of energy makes up for any losses in the resonant circuit consisting of L_1 and C_1.

It is interesting to note the similarity between the circuits shown in Fig. 10A and Fig. 10B. Although we have a vacuum tube used in one circuit and a transistor in the other, there is a great deal of similarity between the two circuits and the way they work. In each case we have energy lost in the resonant circuit being replaced by bursts of energy; from the tube in one case and from the transistor in the other case. Also notice that the energy is fed across only part of the coil in each case, but the voltage induced in the entire coil is enough to set up a current flow that will replace the capacitor charge that is lost because of resistance or other losses in the resonant circuit.

OSCILLATORS USING CAPACITIVE FEEDBACK

There are a number of different oscillator circuits in which capacitive feedback rather than inductive feedback (as in the preceding examples) is used to sustain oscillation. Let's look at some of them now.

Colpitts Oscillator. Perhaps the most important of the oscillators using capacitive feedback is the Colpitts oscillator shown in Fig. 11. The one in Fig. 11A uses a vacuum tube while the one in Fig. 11B uses a transistor.

The operation of the two oscillators is quite similar. When the equipment is first turned on, current flows through L_2, which is the small rf choke used to complete the cathode circuit in Fig. 11A and the emitter circuit in Fig. 11B. Current flowing through the coil produces a voltage drop across the coil, and this charges capacitor C_2. The charge on capacitor C_2 will start an oscillation in the tank circuit, which consists of coil L_1 and two capacitors, C_1 and C_2. Remember that when we have two capacitors connected in series they will act like one capacitor insofar as the coil is concerned, and the circuit will start to oscillate. The voltage developed across C_1 is the feedback voltage. It is applied between the grid and the cathode in the circuit shown in A and between the emitter and the base of the circuit shown in B. When this voltage swings in a direction that makes the end of C_1 connected to C_3 positive and the other end negative, it will increase the current flowing through the tube or transistor, causing an increase in current flow through L_2, which charges C_2 still further. When the polarity of the voltage across C_1 reverses, the voltage will oppose the current flow and in Fig. 11A simply add to the bias between the grid and the cathode, reducing the plate current to zero; or in Fig. 11B, put a reverse bias across the emitter-base junction, reducing the current flowing through the transistor to practically zero.

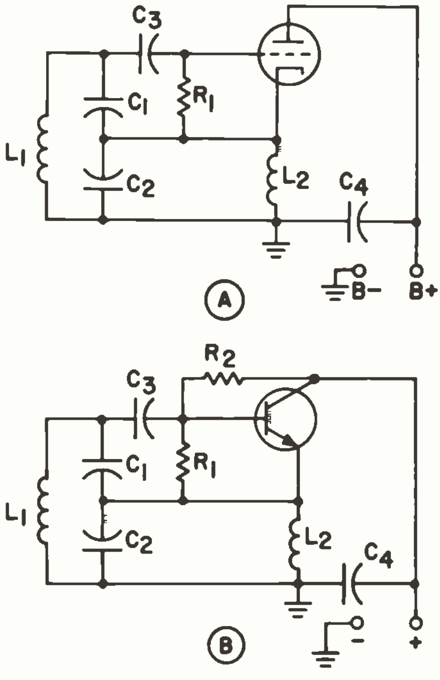

Fig. 11. Two Colpitts oscillators.

The amount of feedback voltage applied to the input of the circuit depends upon the ratio of C_1 to C_2. If C_1 is large compared to C_2, the reactance of C_1 will be low and the reactance of C_2 will be high. Most of the voltage developed across the capacitors will be developed across the higher reactance, in this case C_2. This means that the feedback voltage applied to the input will be low. However, if C_1 is small compared to C_2, the reactance of C_1 will be high compared to the reactance of C_2 and the feedback voltage supplied to the input of the circuit will be high.

The ratio of C_1 and C_2 can be altered to provide the required feedback to the input circuit to sustain oscillation. If the value of C_1 is increased and the value of C_2 decreased by the correct amount, the total capacity in the circuit formed as the result of two capacitors in series remains the same, and hence the resonant circuit of the oscillator does not change.

In some Colpitts oscillators an additional capacitor is connected directly across L_1. This is done to provide some means of changing the resonant frequency so we can vary the frequency at which the oscillator oscillates. It is impractical to try to vary both C_1 and C_2 at the same time, but an additional capacitor placed directly across the coil can be varied, and this will change the resonant frequency of the oscillator. At the same time, since C_1 and C_2 will still form a voltage divider, part of the total voltage developed across the two capacitors in series is fed back to the input circuit; this part can still be controlled by the proper selection of C_1 and C_2.

There are a number of variations of the Colpitts oscillator circuit. It is sometimes found in radio transmitting equipment that must be designed so that its frequency can be varied. The Colpitts oscillator can be designed with excellent frequency stability. By this we mean that once the oscillator is adjusted to operate at a certain frequency it will not drift from that frequency very much. Some oscillators, on the other hand, do not have good frequency stability and will drift appreciably.

Another variation of the Colpitts oscillator circuit is shown in Fig. 12. Here we have the capacitor C_1 connected across L_1 in addition to the voltage divider capacitors C_2 and C_3.

Notice that in this circuit the plate of the tube is fed back directly to L_1, C_1, and C_3 and that the choke coil L_2 has been moved from the cathode circuit to the plate circuit of the tube. The cathode in this oscillator circuit is connected directly to ground.

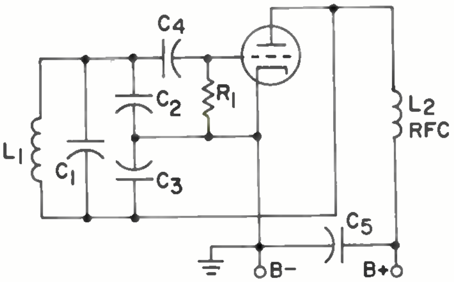

Fig. 12. A variation of the Colpitts oscillator.

In this oscillator when the plate current increases there will be a voltage developed across the rf choke, L_2, in the plate circuit of the tube, and this voltage will charge C_3. Once this capacitor is charged, oscillation starts in the circuit just as in the Colpitts oscillators shown in Fig.11.

The Ultra-Audion Oscillator. Another oscillator that uses capacitive feedback is the ultra-audion oscillator shown in Fig. 13A. When this type of oscillator was first developed, it was considered as a new type of oscillator. However, with careful analysis, we can see that it is actually a Colpitts oscillator, practically identical to the oscillator shown in Fig. 12. We have used the same designations to identify the parts in the circuits shown in Figs. 12 and 13. As you can see, the parts are all the same except for C_2 and C_3, which Fig. 13A does not seem to have. However, in Fig. 13B we have shown these two capacitors. C_2 is the grid-to-cathode capacity of the tube, and C_3 is the plate-to-cathode capacity of the tube. When we consider these two capacities, we have a capacitive voltage-divider network just like the one in Fig. 11. C_2 in Fig. 13B is between the grid and the cathode of the tube. Notice that C_2 in Fig. 12 also is in effect connected between the grid and the cathode of the

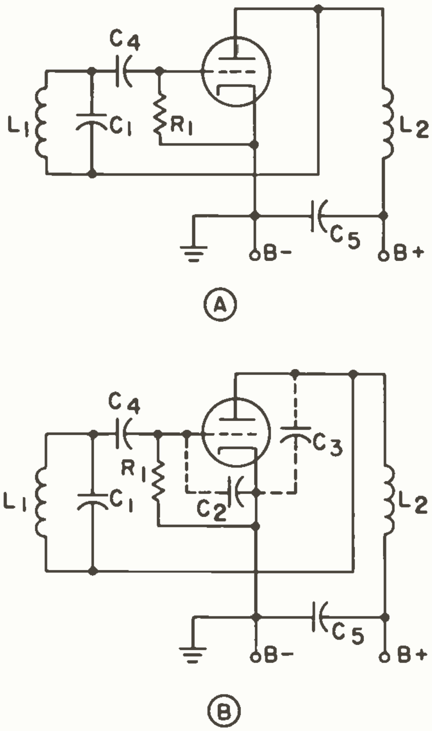

Fig. 13. The ultra-audion oscillator.

tube. C_2 and C_3 are in series in both circuits and they are connected across the tank circuit. C_3 connects directly to the lead going from the plate of the tube to one side of the resonant circuit, and C_2 connects through capacitor C_4 to the resonant circuit. Therefore, this oscillator is simply another form of Colpitts oscillator.

This type of circuit is frequently used in the vhf oscillators in the tuners of television receivers. Of course, it is usually shown in the schematic in the form shown in Fig. 13A. Manufacturers seldom draw in the distributed capacities; they expect the technician to know enough about oscillator circuits to recognize this as the ultra-audion oscillator and to know that this is simply a modified form of Colpitts oscillator.

The Electron-Coupled Oscillator. So far all of the vacuum tube oscillators we have discussed have been triode oscillators. These oscillators are widely used in receiving equipment and are sometimes found in transmitters and other rf power-generating equipment. However, they have some disadvantages, one of which is the direct coupling between the output and input circuits through the grid-to-plate capacity of the tube. Loading the output circuit of the oscillator has an effect on the input circuit and hence often results in an appreciable shift in the frequency at which the oscillator is oscillating. The net result is that triode oscillators are not stable enough for some purposes.

An oscillator that overcomes this difficulty is the electron-coupled oscillator. In this circuit a tetrode or a pentode tube is used so that the only coupling between the input and output circuits is in the electron stream flowing from the cathode to the plate of the tube. Schematic diagrams of two electron-coupled oscillators are shown in Fig. 14. The circuit shown in Fig. 14A is for an electron-coupled Hartley oscillator and the one shown in Fig. 14B is for an electron-coupled Colpitts oscillator.

The operation of these oscillators is similar to the operation of the triode oscillators, except that in the electron-coupled oscillator the screen grid of the tube acts like the plate of a triode tube. In other words, insofar as the oscillator action is concerned, we have three elements in the tube to be concerned about, the cathode, the grid and the screen grid. The screen grid acts like the plate of the oscillator tube. The oscillation is set up in this circuit by these three tube elements. However, the electron stream flows from the cathode of the tube to the plate of

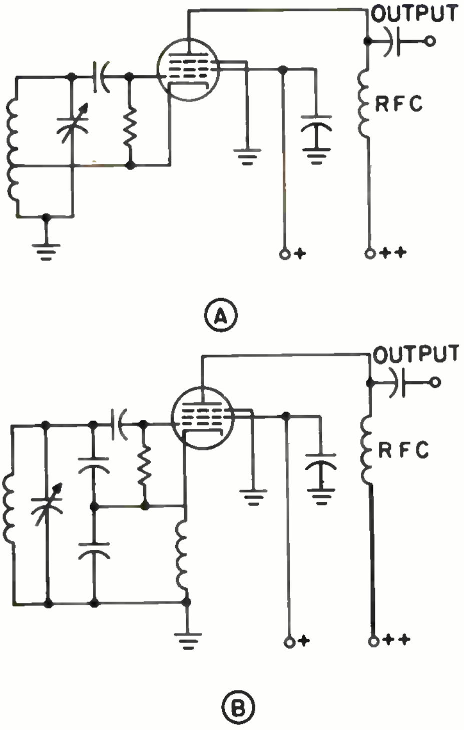

Fig. 14. Electron-coupled oscillators; the circuit at A is a Hartley oscillator.

the tube, and it is controlled by the grid. Since the grid is biased beyond cutoff during most of the rf cycle, but receives a strong positive pulse during a portion of the cycle, the plate current flowing through the tube flows in the form of pulses, which flow only when the grid of the tube is driven in a positive direction.

In the plate circuit of both oscillators we have shown an rf choke and a capacitor through which the oscillator can be coupled to the following stage. In some electron-coupled oscillators you will find a resonant circuit in the plate circuit of the tube instead of the rf chokes shown in Fig. 14. In some oscillators, this resonant circuit will be tuned to the same frequency as the resonant circuit in the grid circuit of the oscillator, but in other oscillators you'll find that it is tuned to a frequency equal to twice or three times the frequency to which the resonant circuit in the grid circuit of the tube is tuned. If we tune the resonant circuit in the plate circuit of the tube to twice the frequency of the resonant circuit in the grid circuit of the tube, we will have a frequency doubler. The resonant circuit in the plate circuit of the tube is set into oscillation by the burst of plate current flowing through the tube. However, since the resonant frequency of this circuit is twice the resonant frequency of the input circuit, the circuit in the plate circuit begins to oscillate at a frequency equal to twice the frequency being generated in the grid circuit. The oscillation in the plate circuit therefore goes through two complete cycles before a second pulse is received from the plate of the tube. This is called a frequency-doubler circuit. If the resonant circuit in the plate circuit is tuned to three times the frequency of the input circuit, the oscillation set up in the plate circuit will go through three complete cycles before it receives an additional pulse from the plate of the tube. This is called a frequency tripler. Now, you might expect this to result in a damped wave, with the amplitude of the cycles which do not receive a reinforcing pulse from the plate of the tube being considerably less than the amplitude of the particular cycles during which the pulse is received. Of course, there will be some loss in the resonant circuit and there will be some change in amplitude. However, by the use of a high Q resonant circuit in the plate circuit, the change in amplitude that occurs each cycle is very small and for all practical purposes all the cycles of the sine wave produced in the resonant circuit will have essentially the same amplitude.

R-C OSCILLATORS

Resistance-capacitance (R-C) oscillators use the charging and discharging action of a capacitor and a resistor in the feedback path to cause oscillation. The R-C oscillator is used in audio and low rf ranges. They offer an inexpensive method of obtaining a fairly stable sine wave within the range of their operation. Although many variations of the R-C oscillators exist, there are only two basic types, the phase shift and the bridge.

The phase shift uses a series of R-C phase shifting circuits between the output and the input to produce a feedback in-phase with the input. The bridge circuit usually uses an additional tube or transistor to obtain the phase shift and a bridge type circuit to control the feedback at the proper frequency.

Phase Shift. The phase shift oscillators in Fig. 15 consist of a conventional amplifier and a phase shift feedback circuit. As in L-C oscillators, the feedback must be positive. In the circuits in Fig. 15A and B, the output signal will be 180° out-of-phase with the input signal. Therefore the phase shift network must shift the phase of the feedback signal 180 degrees. This phase shift is provided by C_1, C_2, C_3 and R_1, R_2, R_3. One section, C_1-R_1, of the feedback loop is shown separately in Fig. 15C. The impedance of the circuits is capacitive and the feedback voltage, e_f, produces a current, i, through C_1-R_1 which leads e_f. The angle of the current lead is determined by the ratio of the reactance of C_1 to the resistance R_1. As the value of R_1 is reduced, the circuit will become more capacitive and more current will lead the voltage up to a maximum of 90°. If resistance is increased the current lead will decrease.

By increasing the number of R-C networks, the losses of the total feedback circuit will decrease and a less amount of phase shift will occur in each section of the feedback loop. For this reason some oscillators use five or six R-C sections. In Fig. 15 each section produces a 60 degree phase shift. The reactance of the capacitors is inversely proportional to the frequency; therefore, only one frequency

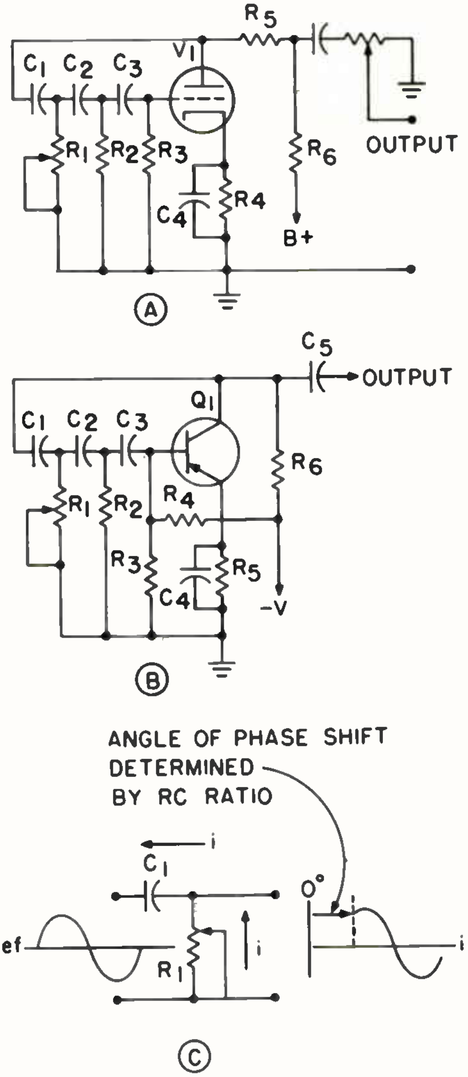

Fig. 15. Phase shift oscillators.

will pass through the feedback loop. Normally the output is fixed in frequency due to the constant value of the capacitors. A variable output may be obtained by using ganged variable capacitors or resistors since an increase in the value of either R or C will decrease the frequency.

Let us examine the operation of the circuit in Fig. 15B. R_3 and R_4 establish the base bias while R_5 and C_4 furnish thermal stabilization and furnish an rf ground to the emitter. R_6 is the load across which the output is taken and C_5 is the coupling capacitor.

Once power is supplied, operation is started by any random noise in the power source or the transistor. This noise causes a change in base current which causes a large change in collector current. This change in collector current develops an output voltage across R_6 which is 180° out-of-phase with the original change in base voltage. Part of the signal developed across R_6 is returned to the base shifted 180 degrees by the R-C network. The shift in phase through the R-C network causes the feedback to aid the output, resulting in positive feedback.

With fixed values of R and C, the 180 degree phase shift occurs at only one frequency, therefore, the output is a sine wave of fixed frequency. At all other frequencies, the reactance either increases or decreases, causing a variation in the phase relationship resulting in degenerative feedback.

The Bridge Oscillator. The Wien-bridge oscillators shown in Fig. 16 consist of low

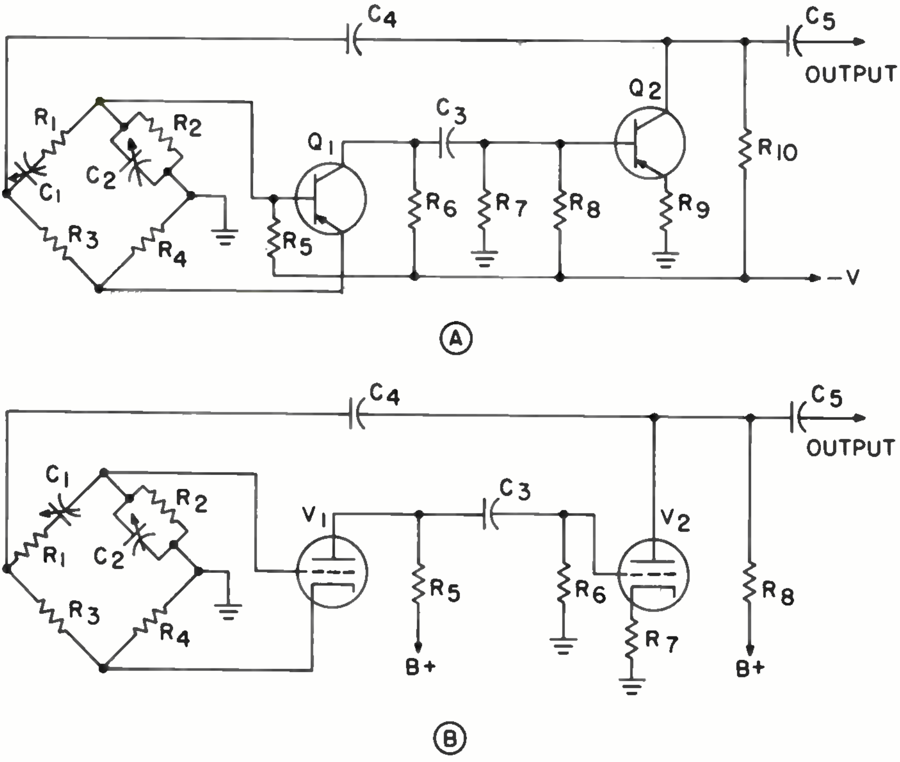

Fig. 16. Wien-bridge oscillators.

gain amplifier stages and a resistive-capacitive bridge circuit. The feedback is taken from the second amplifier and returned to the bridge circuit. Since there are two 180 degree phase shifts between the input of the first amplifier and the output of the second amplifier, the feedback will be positive. The resistive-reactive bridge circuit is designed to be balanced at the operating frequency; therefore, only feedback of the desired frequency reaches the input of the first stage. Let's examine Fig. 16A and see how this works.

The voltage divider, R_2 and R_5 supply base bias for Q_1 and R_7, and R_8 furnishes bias for Q_2. Thermal stabilization is provided by R_4 and R_9. R_3 and R_4 form a resistive leg of the bridge which is in shunt with the output of Q_2. A portion of this output coupled by C_4 and R_3 appears across R_4 as negative feedback. Since R_4 is not frequency sensitive, the negative feedback is constant regardless of the frequency of the output. At frequencies other than the operating frequency, the negative feedback furnished by R_4 will prevent oscillation. At the frequency of operation, which is controlled by the bridge reactive leg of R_1-C_1 and R_2-C_2, the positive feedback to the base of Q_1 is maximum. This in-phase feedback signal is applied to the base of Q_1 and is of sufficient amplitude to overcome the negative feedback across R_4. The total feedback is therefore positive at the operating frequency.

The amplified output of Q_1 is coupled to the base of Q_2 by C_3 and R_7. Q_2 further amplifies the signal and the voltage developed across R_{10} is coupled to the output by C_5, and a feedback signal is coupled through C_4 to Q_1.

We have not covered all of the various L-C and R-C oscillator circuits you are likely to encounter. There are many different variations of the circuits we have discussed, and some entirely different circuits. However, most of the circuits you are likely to encounter will be one of the circuits we have discussed in this section of the lesson or a variation of one of these circuits. If you come across a circuit you do not recognize immediately, first determine whether it is R-C or L-C and, in the latter case, whether capacitive or inductive feedback is used. Once you have decided on the type of feedback that is used, you should be able to figure out how the oscillator circuit works if you keep in mind that its operation is similar to one oscillator we have described in this lesson.

SELF-TEST QUESTIONS

(j) When plate current increases in the tuned grid oscillator (Fig. 9B), what happens to the voltage at the junction of R_1 and C_2?

(k) Where is the feedback voltage developed in the Colpitts oscillator (Fig. 11B)?

(l) The ultra-audion oscillator is a modification of what type oscillator?

(m) How is the 180° phase shift in feedback voltage accomplished in the phase shift oscillator?

(n) What component(s) develops the feedback voltage in the Wien-Bridge oscillator (Fig. 16)?

Crystal Oscillators

Although L-C oscillator circuits have been developed that have very good frequency stability characteristics, the master oscillators in most transmitters still use crystals. Better frequency stability is the main reason for using crystals instead of L-C resonant circuits in master oscillators. The frequency tolerance allowed by the FCC for most transmitting services is very small. The tolerance of a transmitter operating in the broadcast band, for example, is a frequency deviation of only 20 Hertz from the assigned frequency. Some services are permitted slightly more frequency tolerance, but in all cases, the tolerance is rather strict. This restriction is necessary to keep the large number of stations operating in the frequency spectrum from interfering with each other.

Several types of materials can be used for crystals. These include quartz, Rochelle salts, and tourmaline. The most often used crystal material for generating radio frequency signals is quartz. Rochelle salts work better in low-frequency applications, such as in loudspeakers and microphones. Tourmaline will work as well as quartz, but because it is a semiprecious stone, it is more expensive.

The assembly usually referred to as a crystal is composed of a small piece of crystal material mounted in a holder. The crystal material is in the form of a small slab or wafer cut from a larger crystal. The way in which the wafer is cut from the natural crystal determines many of its electrical characteristics. In this section, we will find out how the crystal works, how the crystal is used in oscillator circuits, and finally we will discuss some of the most-used crystal oscillator circuits.

THE PIEZOELECTRIC EFFECT

A quartz crystal exhibits a property called the piezoelectric (pronounced pi-ee-zo) effect when it is compressed mechanically or when a current is applied to it. To illustrate this effect, suppose we have a small crystal wafer with leads attached to its two surfaces. If we squeeze the wafer or bend it in some way, a voltage will appear between the leads. If, on the other hand, we apply a small voltage across the leads, the crystal slab will bend, expand, or contract, depending on the polarity of the applied voltage and the crystal type. These two effects are used in many types of electronic equipment.

A crystal wafer has a definite mechanical resonant frequency at which it will vibrate most readily. This resonant frequency is determined by the physical dimensions of the wafer, particularly the thickness. The thinner the wafer, the higher the resonant frequency. Thus, when an ac voltage, whose frequency is near the crystal resonant frequency, is applied, the crystal will vibrate the greatest amount and produce the greatest output. Because of the large amount of vibration at the resonant frequency, there is a limit to how thin the wafer can be before it becomes too fragile for practical use.

CRYSTAL CUTS

The natural quartz crystal, as shown in Fig. 17, is said to have 3 major axes at right angles to each other. These axes, called the X, Y, and Z axes, are shown in the illustration. The X axis is called the electrical axis; the Y axis is called the mechanical axis; and the Z axis is called the optical axis. The way that the crystal wafers are cut with respect to these axes determines many electrical characteristics, including the frequency range in which the crystal will oscillate and the amount that the resonant frequency will change with changes in the temperature (the temperature coefficient).

If the crystal wafer shown by the shaded section in Fig. 17 is cut so that its face is perpendicular to the Y axis, it is called a Y-cut crystal. Similarly, if its face is perpendicular to the X axis it is called an X-cut crystal. Crystal wafers cut perpendicular to the Z axis have no piezoelectric properties.

Crystal cuts can be made at different angles to the major axes to produce crystals having slightly different electrical characteristics. The type of cut depends on the purpose for which it is to be used.

One of the most important characteristics of a quartz crystal used in oscillator circuits is the amount the crystal frequency varies with variations in temperature. We call this the temperature coefficient of the crystal. Y-cut crystals have a range of about –25 to +100 Hertz/°C/MHz (Hertz per degree centigrade per MHz). In other words, a one-degree centigrade increase in temperature may cause the frequency to decrease as much as 25 Hertz, or increase by as much as 100 Hertz for each MHz of the frequency for which the crystal is ground. To take an extreme case, the frequency of a 4-MHz crystal might increase by 400 Hertz for each degree of temperature change. Because of this rather high temperature coefficient and also because Y-cut crystals have a tendency to oscillate at a second frequency near the design frequency, they are seldom used.

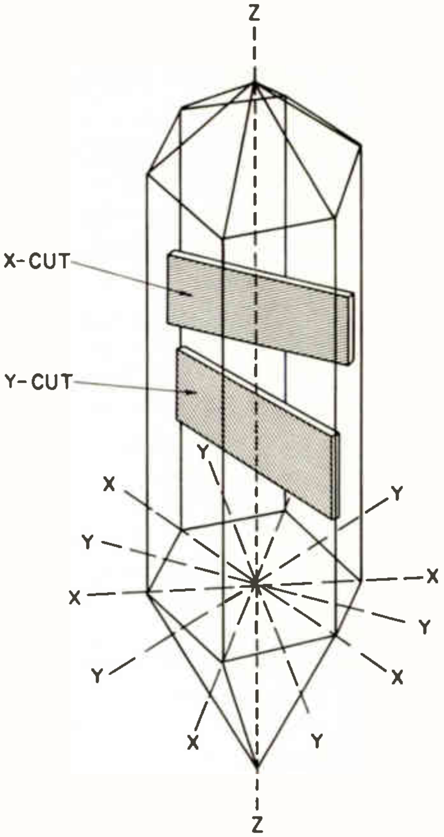

Fig. 17. Major axes quartz crystal.

X-cut crystals have a range of about –10 to –25 Hertz/°C/MHz. The minus sign means that the crystal frequency decreases with an increase in temperature. We call this a negative temperature coefficient. Even though the frequency variation is less, close temperature control is still required to keep the crystal oscillating at the correct frequency.

As an example of how temperature affects the crystal frequency, consider an X-cut crystal that has an operating frequency of 4650 kHz at 50° C. If it has a temperature coefficient of −20 Hertz per degree centigrade per MHz, let's determine what its operating frequency would be if the temperature changes ten degrees.

4650 kHz = 4.65 MHz

therefore the change in frequency per degree centigrade is:

4.65 X 20 = 93.00 Hertz

The change in frequency with a temperature change of ten degrees will be:

93 X 10 = 930 Hertz
and 930 Hertz = .930 kHz

Thus we see that with a temperature change of only 10 degrees, the frequency will change almost 1 kHz. With a 20-degree change, the frequency change would be almost 2 kHz. If the temperature increases 10°, the frequency will decrease to about 4649 kHz (4649.07 kHz), and if the temperature drops 10°, the frequency will increase to almost 4651 kHz (4650.93 kHz). Where there are many stations operating on frequencies close together, this shift in frequency could be enough to cause interference.

We can reduce the temperature effect on the resonant frequency of the crystal by cutting the crystals at angles to the major axes. Examples of such crystal cuts, called the AT-cut and the BT-cut, are shown in Fig. 18. These crystals are really Y-cut crystals with the face of the wafer at an angle of about 39° to the Z axis instead of parallel to it in the case of the AT-cut crystal, and about 45° to the Z axis in the case of the BT-cut crystal. Notice that the angle of the AT-cut crystal is opposite to that of the BT-cut crystal with respect to the Z axis. The temperature coefficient of these cuts is about ±2 parts per million at a temperature of 40°C to 50°C. Thus, the angle cut practically cancels the effects of temperature variation on the frequency of oscillation if it is operated within the temperature range.

Other angular cuts can be made to get other electrical characteristics and effects. Some examples are the CT and DT cuts used for lower frequency operation below 500 kHz. A CT-cut crystal is cut perpendicular to the BT-cut crystal, and the DT cut crystal is cut perpendicular to the AT-cut crystal. Another cut is the GT cut.

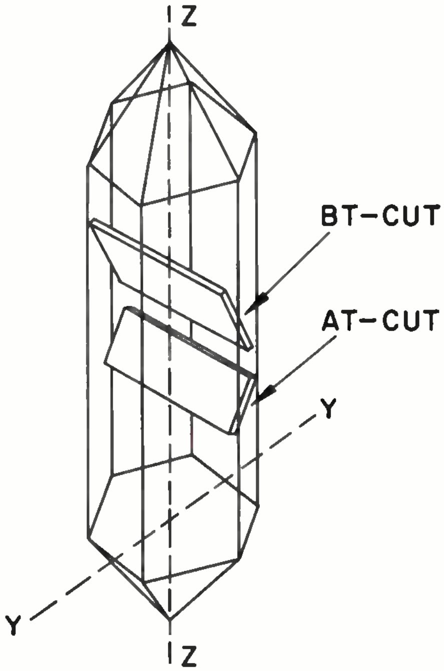

Fig. 18. AT-cut and BT-cut crystals are cut on an angle to the Z axis as shown.

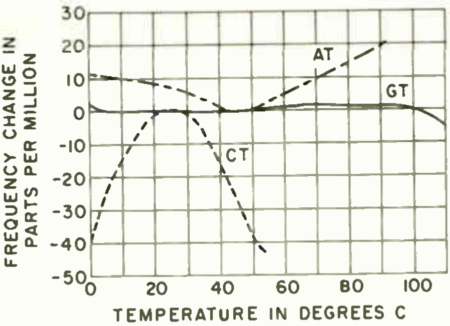

Fig. 19. Frequency changes of different crystal cuts with changes in temperature.

This crystal is cut on an angle of about 45° to either the CT- or DT-cut crystals.

Fig. 19 illustrates the variation of the resonant frequency with temperature for various crystal cuts. Notice that the frequency of the GT-cut crystal is practically constant from 0° to about 100° This cut, therefore, is the best to use in equipment that will be subjected to wide temperature variations. The other cuts have zero temperature coefficients at or near specific temperatures.

CRYSTAL HOLDERS

After the crystal has been ground, or etched by means of chemicals, until it is of the proper thickness, it is placed in a holder. The holder is then sealed so that no air, dirt, or oil can reach the crystal wafer. These can cause erratic operation of the crystal. A crystal in its hermetically sealed holder is shown in Fig. 20.

There are two ways of mounting the crystal in the holder. In one way, a very thin film of metal is formed directly on the surface of the crystal by spraying or firing. The metal can be either silver, gold, or aluminum. The crystal is supported by flexible wires fastened to this metallic film with solder having a low melting point. The leads are attached to a node or non-oscillating portion of the crystal. The node can be either in the center of the crystal face or at an edge where inhibiting the vibrations will do no harm.

Another method of mounting the crystal in a holder is to arrange it so that it is pressed between two metal plates. The metal plates make electrical contact with the crystal surfaces. Another type uses an air gap .001 to .005 inch thick between the crystal and the upper plate. This air gap produces a damping effect on the amount of crystal vibration. Often, however, the crystal holder is evacuated so that the damping will be reduced.

Regardless of the type of mounting used, the holder itself is designed to keep the crystal free of grit, dirt, and oil film. Even a speck of dirt or a greasy film can change the characteristics of the crystal. Therefore, the crystal holder should never be opened, nor should the crystal be handled. If it is ever necessary to take one apart, the crystal may be cleaned with a

Fig. 20. A quartz crystal in its holder.

good nonflammable commercial cleaner. The crystals should be handled with clean, lint-free cloths, not with bare fingers (bare fingers leave traces of perspiration on any object they touch).

Equivalent Circuit. The symbol in Fig. 21A is used in schematic diagrams to represent the crystal in its holder. The equivalent electrical circuit of the crystal and holder assembly is shown in Fig. 21B. As you can see, we have here a series-parallel circuit composed of the series components L, R, and C_1 shunted by capacity C_2. The crystal, therefore, acts electrically as an L-C circuit; as an inductance at frequencies above the resonant frequency and as a capacitance at frequencies below resonance. The apparent inductance L is due to the mass of the crystal, resistance R is the result of internal mechanical losses, and capacity C_1 is the stiffness (piezoelectric properties) of the crystal. Capacity C_2 is the capacity between the electrode plates, with the quartz crystal acting as the dielectric.

Since the crystal acts as an electrical resonant circuit, we would expect it to be frequency selective; that is, it will oscillate more vigorously at its natural resonant frequency than at any other frequency. This is true. When an ac voltage is applied to its electrodes, the crystal generates an alternating potential of its own.

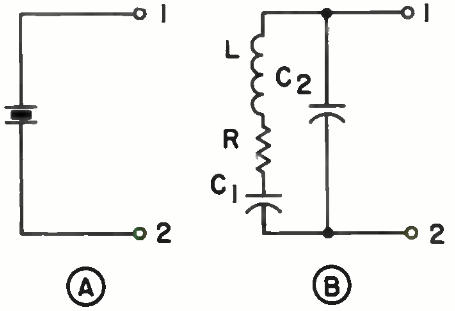

Fig. 21. The schematic symbol for a quartz crystal in its holder is shown at A. The equivalent electrical circuit of a quartz crystal is above at B.

Because of its electrical characteristics, the crystal can be used in an oscillator circuit. The electrical properties of the crystal are somewhat different from those of a typical coil and capacitor. The mechanical properties of the crystal produce a very high apparent inductance, L. Also, since the mechanical losses during vibration are small, the electrical equivalent resistance is also very small. When we have an L-C circuit containing a large inductance and a very low resistance, the Q of the circuit will be very high. This is the case with the crystal used in oscillator circuits.

Practical crystals have effective Q values which are about 100 times as great as that ordinarily obtainable with the usual inductance coil and tuning capacitor. Crystals, therefore, have extremely good frequency selectivity. The higher the Q, the better the frequency stability. Thus, if we substitute a crystal for the ordinary L-C tank circuit, we can make an oscillator that has good frequency stability.

CRYSTAL OVENS

The purpose of a crystal oven is to maintain the crystal at a constant temperature to prevent frequency drift. Some time ago, it was common practice to put the crystal, the entire master oscillator of the transmitter, and often even the buffer stage in a heat-controlled chamber. This prevented temperature variations from affecting the physical dimensions of the coil and capacitor in the plate circuit, and

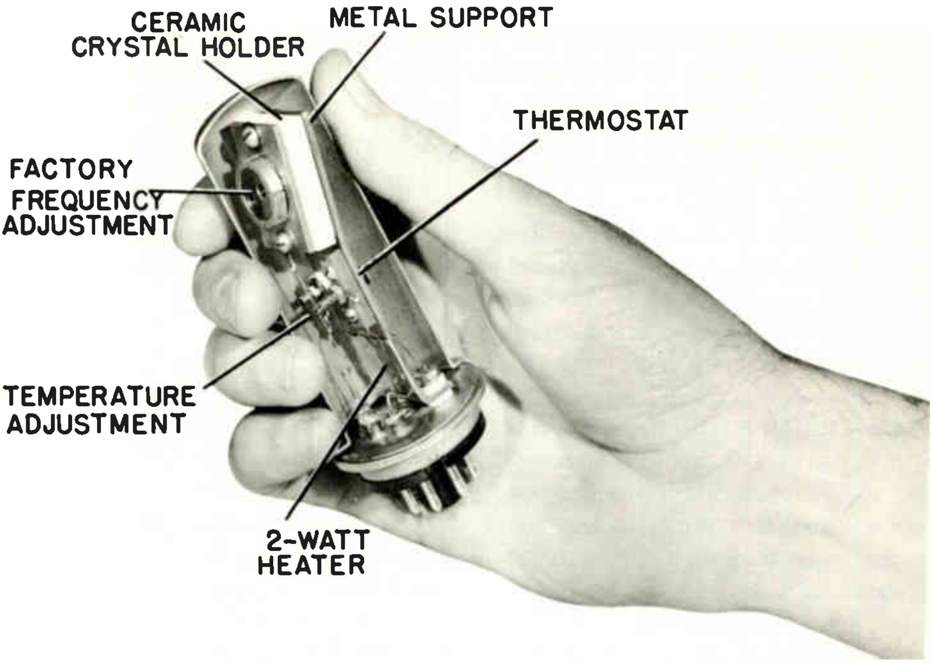

Fig. 22. A cut-away view of a crystal oven.

thus changing the oscillator frequency. This is seldom done in modern transmitters; generally only the crystal is temperature-controlled.

A typical modern crystal oven is shown in Fig. 22. The overall unit is about the size of a metal receiving tube -- about 4 inches high and 1-1/4 inches wide. Smaller units are also available. The crystal oven unit fits into an octal tube socket. The unit in Fig. 22 is guaranteed to hold the transmitter frequency within 10 Hertz at any point on the broadcast band.

The crystal is contained in a ceramic holder attached to a copper support. The heater is also wrapped around this support. Thus, the metal support conducts the heat to the crystal and maintains it at a constant temperature.

The heat is controlled by a bimetallic thermostat attached to the metal support. When the temperature of the support drops a very small amount, the thermostat contacts close, and current is applied to the heater. When the support reaches a certain temperature, the thermostat contacts open. The difference between the on and off temperatures of the thermostat is very small; that is, the temperature must drop only a small amount before current is again applied to the heater coil.

The crystal frequency and thermostat temperature adjustments shown in Fig. 22 are set at the factory when the unit is assembled. It is impossible to change the adjustments because the unit is hermetically sealed. Thus, when ordering such a crystal unit, you must specify the exact crystal frequency you want and the circuit in which the crystal will be used. Crystal manufacturers will not guarantee the operating frequency of a crystal unless the crystal is adjusted in the circuit in which it will be used.

CRYSTAL OSCILLATOR CIRCUITS

To help see how the crystal oscillator works, let's look at another L-C oscillator. This oscillator is shown in Fig. 23, and is called a tuned-grid, tuned-plate oscillator. It is easy to see where this oscillator gets its name, since there are resonant circuits in both the grid circuit and the plate circuit of the tube.

The tuned-grid, tuned-plate oscillator works because of the capacity between the plate and grid of the triode tube. When the resonant circuit in the plate circuit of the tube is tuned to a frequency slightly lower than the operating frequency, it will act like an inductance. Under these conditions, the phase of the signal voltage fed from the plate of the tube back to the grid of the tube is correct to aid the ac grid voltage, and oscillation occurs.

The crystal oscillator shown in Fig. 24 is simply a modification of the tuned-grid tuned-plate oscillator shown in Fig. 23. Here a crystal has been substituted for the resonant circuit in the grid circuit of the oscillator and a milliameter is shown in the plate circuit of the stage to measure plate current. Actually almost all oscillators have some provision made for measuring plate current.

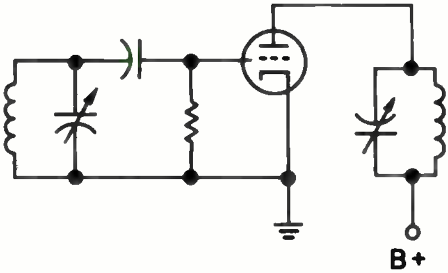

Fig. 23. A tuned-grid, tuned-plate oscillator.

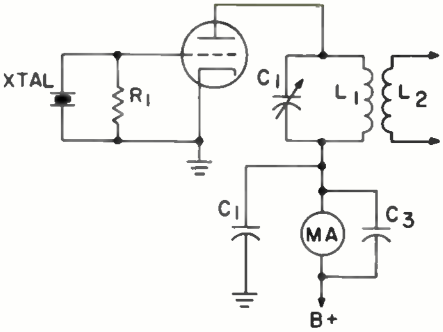

Fig. 24. A simple crystal-oscillator circuit.

Since the crystal is the equivalent of the circuit that has been removed, the crystal oscillator operates in exactly the same way as the resonant circuit in the grid of the tuned-grid, tuned-plate oscillator. The plate circuit must be tuned so that it presents an inductive load, and energy will be fed from the plate of the tube back to the grid in the correct phase to aid the ac grid voltage so oscillation will occur.

In the input circuit, the rf current flowing through the crystal itself is limited only by the resistance of R_1. This resistance is usually low enough to result in a fairly high crystal current. If the resistance is made too high, the crystal may be somewhat erratic as it starts to oscillate when power is applied to the stage. On the other hand, if the current becomes higher than about 100 milliamperes, the crystal vibrations may be so violent that the crystal may shatter, and thus destroy itself. Of course, the thinner the crystal and the higher its resonant frequency, the lower the safe current limit becomes.

Many transmitters have an rf current

meter in series with the crystal to indicate this current. To prevent possible damage to the crystal, the amplitude of oscillation in a crystal oscillator circuit must be kept at a safe level. Usually this is accomplished by keeping the plate voltage on the oscillator tube low. This low plate voltage reduces the maximum output power that can be obtained from such oscillators.

Pierce Oscillator. It is possible to place the crystal between the plate and grid circuits, as shown in Fig. 25, instead of between the grid and cathode. In this case the circuit is similar to the ultra-audion circuit. This circuit is called the *Pierce* oscillator.

Notice that the circuit contains no tank inductance or tuning capacity. The amount of feedback and the grid excitation can be controlled to some extent by adjusting the capacity of C_1. The larger this capacity, the less the feedback. The exact capacity of C_1 in most cases is not critical. Usually, when the best value is determined, crystals of slightly different frequency can be switched into the circuit without further adjustment. Again the plate voltage must be low to prevent damaging the crystal.

Crystal Oscillators Using Multi-Grid Tubes. Tetrode and pentode tubes also may be used in crystal-oscillator circuits. These tubes have less plate-to-grid capacity than do triodes, and therefore, there is less feedback current to the grid when they are used as crystal oscillators. The lower feedback means that these tubes can be operated at a higher output power than a triode without excessive rf crystal current.

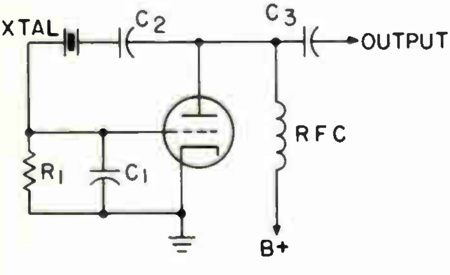

Fig. 25. The basic Pierce oscillator.

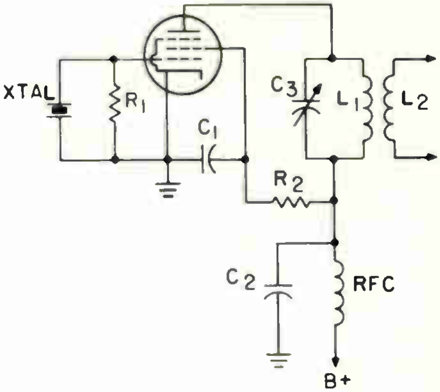

Fig. 26. Crystal oscillator using a pentode tube.

A crystal oscillator using a pentode tube is shown in the diagram of Fig. 26. Because of the limited amount of plate-grid feedback, the plate voltage can be considerably higher than for the triode oscillator. This, of course, increases the output power. The circuit may also be used for high-frequency crystals having fundamental resonant frequencies of about 10 MHz. The output in this case can be high, but the small amount of current through the crystal protects it from excessive vibration. Sometimes extra feedback is needed to produce oscillation in the circuit. This is done by connecting a small capacitance between the plate and the control grid.

Crystal Control Transistor Oscillators. A transistor tickler coil oscillator using a crystal to control feedback is shown in Fig. 27. Positive feedback from collector to base is provided through the mutual

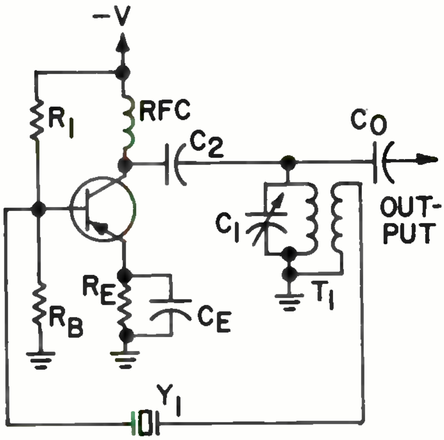

Fig. 27. Crystal tickler coil oscillator.

inductance between the windings of T_1. This provides the 180° phase shift necessary to sustain oscillation. In this circuit, the crystal acts as a series resonant circuit. At frequencies other than the resonant frequency the crystal acts as a high impedance, blocking the feedback path. At the resonant frequency the crystal offers minimum impedance to the feedback signal. The operating frequency may be varied by the use of different crystals and tuning the tank to the frequency of the crystal with C_1.

The crystal oscillator shown in Fig. 28 is a variation of the Colpitts oscillator. In this circuit the crystal acts as a parallel tuned circuit and replaces the L-C tank. Operating frequency is determined by the crystal and the capacitance in series with it. At the resonant frequency, the crystal and capacitors in parallel with it form a high impedance tank circuit. Capacitors C_1 and C_2 form a voltage divider that is center-tapped to ground. The voltage developed across C_1 is applied between the base and ground providing a 180° phase shift in the feedback path.

OVERTONE OPERATION

Most crystals will oscillate not only at their fundamental resonant frequencies, but also at odd overtones of the fundamental. A crystal with a fundamental of 4 MHz, for example, will oscillate also at frequencies near 12 MHz, 20 MHz, 28 MHz, etc. The oscillation frequency will not be an exact multiple of the fundamental oscillation frequency. Exact multiples would mean harmonic operation rather than overtone operation. Thus, if you use a crystal designed for fundamental operation as an overtone crystal, you can use the frequency markings on the crystal holder only to get an approximate idea of the actual frequency at which the oscillator is working. To determine the exact frequency, you will have to measure it with a frequency meter.

Although any crystal can be used in overtone operation, it is best to use one that has been ground specifically for this purpose. The ordinary fundamental type of crystal is somewhat unstable and hard to adjust when operated on an overtone. Most of the overtone crystals are designed

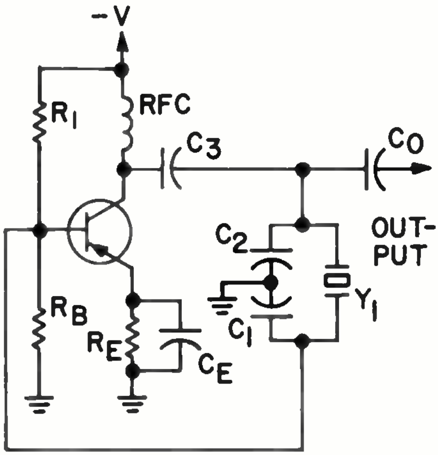

Fig. 28. Colpitts crystal oscillator.

to operate on the third overtone; operation at higher overtones is possible, but the stability and ease of adjustment becomes more critical at the higher overtones.

The chief advantage of overtone operation is that we can generate frequencies in the vhf range without the use of doubler stages. The highest fundamental oscillation frequency of a crystal is about 10 MHz. If one is ground to operate on a higher frequency then it is so thin that it breaks easily. Thus, by operating it on the third or fifth harmonic, we get a much higher frequency than we could on the fundamental. Another advantage of overtone operation is that no frequencies are generated that can cause interference with other channels. Because the number of frequency multiplier stages is reduced or completely eliminated, overtone crystals are used often in mobile, marine, and aircraft transmitters in which compactness is important.

The oscillator circuit using an overtone crystal is similar to an ordinary crystal oscillator circuit of the type you will study later. The overtone at which the crystal will operate is determined by the plate circuit resonant frequency. The circuit of an overtone oscillator is shown in Fig. 29. The oscillator uses a crystal having a fundamental frequency of about 8 MHz to give a 24 MHz output when operated on the third overtone.

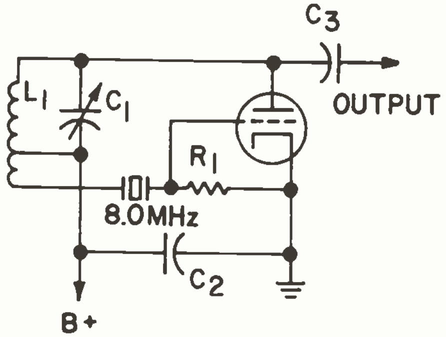

Fig. 29. An overtone oscillator circuit.

In Fig. 29, the circuit made up of C_1 and the upper end of L_1 is resonant at 24 MHz. The tap on L_1 is held at rf ground potential by C_2. The lower end of L_1 is inductively coupled to the upper end (usually this is a simple one-tapped coil) so energy is fed from the plate circuit back to the grid circuit to sustain oscillations. The rf signal fed back to the grid circuit will cause the crystal to oscillate on its third overtone frequency. Output from the oscillator is taken from the plate circuit through C_3.

Modern overtone crystals are capable of oscillating as high as 100 MHz on higher order harmonics, so the output of a crystal oscillator could be up in this region. However, when such high frequency signals are needed, you will often find a crystal oscillator operating at 50 MHz followed by a doubler to increase the frequency to 100 MHz, or an oscillator operating at about 33.3 MHz followed by a tripler.

An oscillator circuit that can be used to generate both even and odd harmonic frequencies of the fundamental is the tri-tet circuit shown in Fig. 30. The output signals are harmonics rather than overtones.

The tri-tet circuit is actually the crystal version of the electron-coupled circuit described earlier in this lesson. The crystal and the resonant tank L_1-C_1 are connected to the control grid, the cathode, and through C_4 to the screen grid (which acts as the oscillator plate), to form a modified tuned-plate, tuned-grid oscillator. The cathode tank circuit L_1-C_1, therefore, must be tuned to a frequency slightly lower than that of the crystal in order to be inductive.

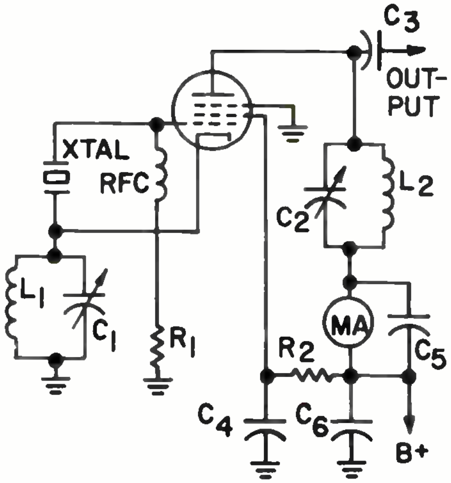

Fig. 30. The tri-tet oscillator circuit.

Since the screen grid is bypassed to ground by capacitor C_4, there is very little direct coupling between the actual tube plate and the oscillator portion of the circuit. The electron stream reaching the plate, however, arrives in the form of pulses that contain relatively large amounts of harmonic energy. If we tune the plate tank circuit L_2-C_2 to a frequency twice that of the crystal, a considerable amount of output power at the second harmonic frequency will be obtained. Even if the plate is tuned to a frequency three times that of the crystal we will get a fair amount of third harmonic output power.

Therefore, the tri-tet circuit not only behaves as a crystal-controlled oscillator, but also performs as a frequency doubler or tripler at the same time. The additional feature of the electron coupling prevents load variations from reaching the crystal and influencing the oscillator frequency. A disadvantage of this circuit is that both sides of the crystal are above rf ground potential. Another is the fact that a cathode coil is needed.

CRYSTAL-OSCILLATOR ADJUSTMENT

The tuning procedures for crystal oscillator circuits of all types are similar. The curves in Fig. 31 show how the plate current of an oscillator tube varies with changes in the tuning capacity. The solid curve is for an unloaded oscillator circuit, and the dashed curve represents the circuit loaded.

When you adjust a triode or Pierce oscillator like those shown in Figs. 24 and 26, begin first with the plate tank capacitor in the minimum capacity position. Then rotate the capacitor toward the maximum capacity position. As soon as oscillation begins, the plate current will begin to decrease. It will decrease more and more, going through points 3 and 2 in Fig. 31 as oscillation becomes stronger. If the plate capacitor is turned too far, however, oscillations will stop abruptly as at point 1 in Fig. 31. In practice, it is best not to approach point 1 too closely because minor voltage or current variations may stop the oscillator. Instead, adjust the plate tuning capacitor so that operation will be somewhere in the stable region between points 2 and 3.

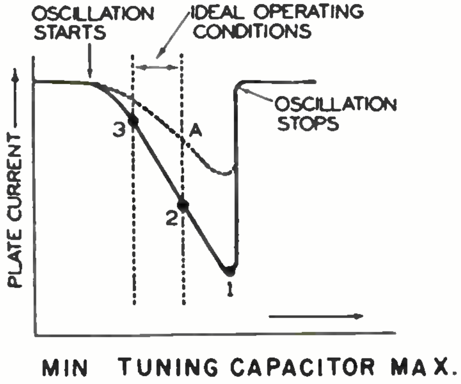

Fig. 31. Curves showing how the plate current in a crystal-oscillator circuit varies with tuning.

When a load is placed on the oscillator circuit, the plate current dip of the oscillator will not be as pronounced. It will follow the dashed curve in the diagram. As before, however, too much capacity will cause the oscillator to stop. The operating point again should be somewhere between points 2 and 3.

The transistor oscillator in Fig. 27 would be adjusted in a similar manner, C_1 being tuned to a point where the current through the tank is between points 2 and 3 in Fig. 31. C_1 is first tuned for minimum capacitance. Then the capacitance is increased until current is between the stable points of operation.

When adjusting the tri-tet circuit in Fig. 30, first set the cathode tank capacitor C_1 to a frequency higher than resonance (minimum capacity) so that oscillations will occur. In this circuit, the usual parts values are such that oscillation will be maintained over a fairly wide range of C_1 adjustment. However, the crystal current increases very rapidly as the capacity is increased. Start tuning C_1 for the minimum capacity position and progress only to the point of normal crystal current. Usually an rf milliammeter is placed in series with the crystal to measure this current. The current should be kept below 100 milliamperes.

With no load connected, the plate tank capacitor C_2 should be adjusted for a minimum value of plate current as indicated by a sharp dip in the meter reading. Now, connect the load to the circuit. This is usually the grid of the following buffer amplifier stage. With the load attached, capacitor C_2 may need readjustment to bring the plate current back to minimum. This time, however, the current value will be somewhat higher because of the loading.

Finally adjust the cathode tank capacitor C_1 for maximum harmonic power output which will be indicated by a maximum current flow in the following amplifier grid current. Also watch the crystal current to be sure that it does not rise above the safe limit.

FREQUENCY SYNTHESIZERS

In order for a transmitter to be versatile, it must be capable of operating on more than one frequency. In the crystal oscillators discussed previously we have to change the crystal each time the frequency is changed. Thus for each channel the equipment is operated on, we need a separate crystal. Transmitters that are operated on only a few channels use separate crystals for each channel. However, this arrangement is not completely satisfactory when the transmitter must be capable of operating on a large number of channels. The frequency synthesizer is one solution to this problem.

A frequency synthesizer is basically a circuit in which harmonics and subharmonics of one or more crystals are combined to provide a variety of output signals. The same principle is used that you studied earlier in the basic superheterodyne receiver. You will recall that in the mixer stage of that receiver the incoming signal was beat with the local oscillator to form two new frequencies. These new frequencies were equivalent to the sum and the difference of the incoming signal frequency and the local oscillator frequency.

Fig. 32 shows one type of frequency synthesizer. Circuit details have been omitted for simplicity. Two oscillator circuits are used with a mixer which will beat the outputs of the oscillators together and produce an output equal to

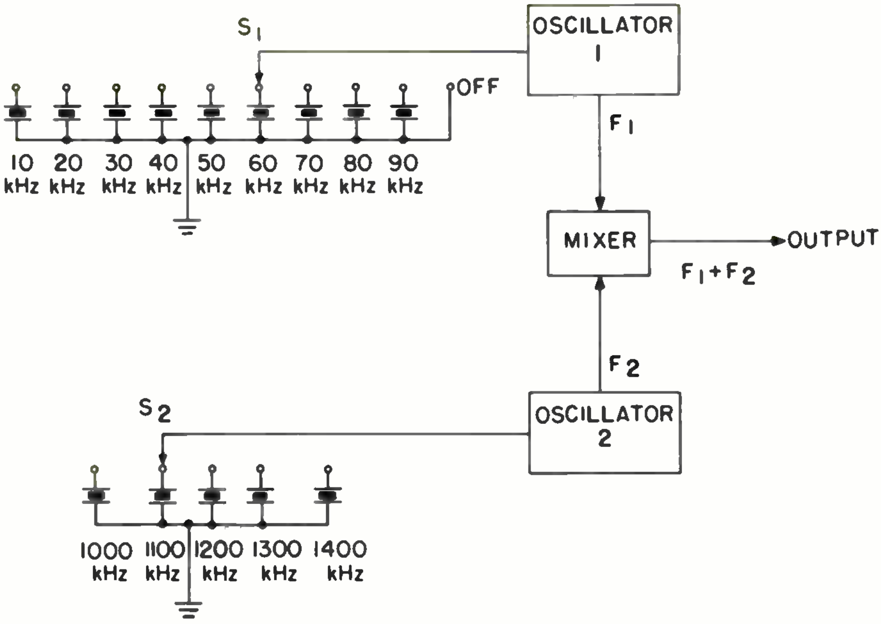

Fig. 32. Multiple crystal frequency synthesizer.

the sum of the two frequencies. Each of the oscillators is tunable to different frequencies of a selected band by switching the crystals in the oscillator circuit.

Oscillator number 1 has 9 crystals in the input. Each crystal is resonant at a different frequency, enabling the output of oscillator number 1 to be varied in 10 kHz steps from zero to 90 kHz. The tenth position of switch S_1 disables the oscillator. Oscillator number 2 has 5 crystals which vary its frequency over a 500 kHz band in 100 kHz steps.

With S_1 and S_2 in the positions shown, oscillator 1 is operating at 60 kHz and oscillator 2 at 1100 kHz. The mixer receives both outputs and beats them to form a 1160 kHz output. If S_2 was left in this position and S_1 moved, the output of the mixer could be varied from 1100 kHz (when S_1 is in the off position) to 1190 kHz in 10 kHz steps. By moving both switches, the output can be varied from 1000 kHz to 1490 kHz in 10 kHz steps. In this manner, a total of 50 different frequencies can be generated from only 14 different crystals.

This type of synthesizer has the advantage of less crystals than a conventional oscillator with similar frequency coverage.

Let's look at a block diagram of a transceiver and see another use for frequency synthesizers.

The transceiver is a compact radio station that uses some of the components for both transmitting and receiving. These units usually transmit and receive on the same frequency.

Fig. 33 is a block diagram of a transceiver. The upper channel is the receiver section while the lower channel is the transmit section.

Incoming rf is coupled from the an-

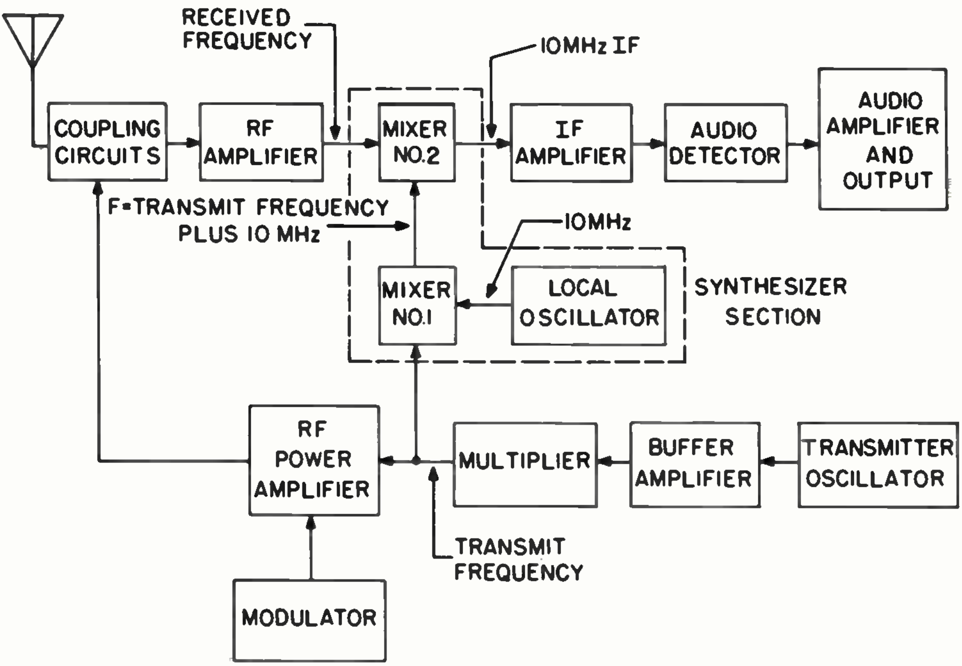

Fig. 33. Block diagram of a basic transceiver.

tenna to the rf amplifier. This amplified rf is then heterodyned in mixer number 2 with a signal from mixer number 1. We will discuss the signal from mixer number 1 shortly. The difference frequency is detected and sent through the i-f amplifiers to the audio detectors and output section.

The transmit channel gets its frequency from the transmitter oscillator. After being multiplied to the proper frequency, the rf is fed to the power amplifier. In the power amplifier the modulating signal is applied to the rf. The rf, now containing the intelligence, is coupled from the power amplifier to the antenna.

Notice that between the multiplier and the power amplifier, the transmitter frequency is fed to mixer number 1. This is part of the frequency synthesizer.

You recall that the i-f is the difference between the local oscillator and the incoming rf. Let's assume in this example that we desire a 10 MHz i-f. In that case our local oscillator frequency to mixer number 2 must be 10 MHz above the incoming rf. Since the transmitted rf and received rf must be the same frequency for stations to communicate with each other, a separate oscillator is required to generate the local oscillator frequency.

If a synthesizer were not used, the local oscillator crystal would have to be changed each time the transmitter oscillator crystal was changed in order to keep the local oscillator 10 MHz above the transmitter frequency. The synthesizer however, uses a very stable constant frequency oscillator operating at the 10 MHz i-f. The transmitted rf is fed to mixer number 1 of the synthesizer where it is mixed with the 10 MHz signal. The sum of these two frequencies is then used as the local oscillator frequency. In mixer number 2 the local oscillator frequency is mixed with the incoming rf and the difference (10 MHz) is used as the i-f.

In this manner the local oscillator frequency to the receiver is changed each time the transmitter frequency is changed. Therefore the local oscillator frequency is always 10 MHz above the received frequency. This eliminates the need to use a different crystal in the receiver local oscillator each time the transmitter frequency is changed.

There are many types of frequency synthesizer circuits in modern communication equipment. They all operate on the same principle of combining two or more frequencies to generate an output frequency. From this discussion you should be able to understand the basic fundamentals of any frequency synthesizer you encounter.

SELF-TEST QUESTIONS

(o) Why is plate voltage kept low in the Pierce oscillator?

(p) Describe how frequency is controlled in the oscillator in Fig. 27.

(q) What is the advantage of overtone operation?

(r) In the multiple crystal frequency synthesizer in Fig. 32, what is the output of the mixer if S_1 is in the 80 kHz position and S_2 is in the 1300 kHz position?

(s) In addition to performing as an oscillator, what other function is accomplished by the tri-tet oscillator?

Nonsinusoidal Oscillators

The oscillators you have studied up to this point have all been sine wave oscillators; that is, their output is a sine wave. In this section we will look at nonsinusoidal oscillators. There are many circuits that can be classed with this group of oscillators but we are primarily interested in only two; the multivibrator and the blocking oscillator. After we complete our study of the basic circuits, we will see how these circuits are used in communication equipment.

An oscillator circuit in which the output is a nonsinusoidal waveform is generally classified as a relaxation oscillator. The relaxation oscillator uses a regenerative circuit in conjunction with an R-C circuit to provide a switching action. The charge and discharge time constants of the R-C components are used to control the shape and frequency of the output waveforms.

THE MULTIVIBRATOR

The multivibrator is essentially a nonsinusoidal two-stage oscillator in which one stage conducts while the other is cut off until a point is reached at which the stages reverse their conditions. This oscillating process is normally used to produce a square wave output. A multivibrator that operates continuously with first one stage conducting and then the other is called a free running or astable multivibrator.

The multivibrator in Fig. 34 is a two stage R-C coupled, common-emitter amplifier with the output of the first stage coupled to the input of the second stage and the output of the second stage coupled to the input of the first stage. Since the signal in the collector circuit of a common-emitter amplifier is reversed in phase with respect to the input signal, a portion of the output of each stage is fed to the other stage in-phase with the signal at the base. This regenerative feedback with amplification is required for oscillation. The output of this multivibrator is a square wave whose frequency is determined by the R-C time constant in the feedback loops.

Forward bias for the base of Q_1 is obtained through the low resistance emitter-to-base junction in series with R_2 across the power supply. In a similar manner, bias for the base of Q_2 is obtained through the emitter-to-base junction and R_3. When the power supply is first energized the current that flows through each collector load resistor, R_1 and R_4, is determined by the effective resistance of Q_1 and Q_2 for a given value of base bias voltage. Due to slight differences in the transistors, more current will flow in one transistor than in the other.

For the purpose of this explanation,

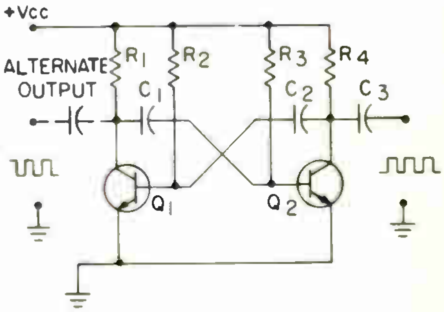

Fig. 34. Astable multivibrator.

assume that initially more collector current flows through Q_1 than Q_2. Thus as collector current in Q_1 increases, the voltage at the junction of R_1 and C_1 decreases. In other words, the collector of Q_1 becomes less positive. This negative going pulse is coupled through capacitor C_1 to the base of Q_2. As the collector current in Q_1 continues to increase, the signal coupled to the base of Q_2 continues to become more negative. As this negative signal overcomes the positive bias established by the emitter-to-base junction and R_3, collector current in Q_2 starts to decrease.

With collector current in Q_2 decreasing, the voltage at the junction of C_2 and R_4 starts to increase. This positive rise in voltage is coupled to the base of Q_1 through capacitor C_2. The positive going pulse at the base of Q_1 aids the foward bias already established by R_2 and the emitter-to-base junction of Q_1. This causes collector current in Q_1 to continue to increase. This regenerative process continues until Q_1 is driven into saturation and Q_2 is cut off.

When Q_1 is saturated, its collector current no longer increases but becomes a constant value, therefore, there is no further change in collector voltage to be coupled through C_1 to the base of Q_2. In a similar manner, Q_2 is cut off so there is no further change in its collector voltage to couple through C_2 to the base of Q_1.

With no positive pulse coupled from Q_2 to Q_1, the base of Q_1 is only a few tenths of a volt positive. C_2 quickly charges through the low resistance of the base to the emitter junction of Q_1 and R_4 to a potential approximately equal to the power supply voltage. The heavy conduction of Q_1 places its collector voltage at nearly ground potential. C_1, which was previously charged with a negative potential at the junction of C_1 and R_3, starts to discharge through R_3 at a time constant of R_3-C_1.

As C_1 discharges, the voltage at the base of Q_2 becomes less and less negative until a point is reached where reverse bias is no longer applied and Q_2 goes into conduction.

When Q_2 starts to conduct, collector current begins to flow through R_4, collector voltage at Q_2 decreases, and a negative going pulse is coupled through C_2 to the base of Q_1. As C_1 continues to discharge, collector current in Q_2 continues to increase and the pulse coupled to the base of Q_1 goes more negative. As this negative signal increases, Q_1 decreases its conduction. This results in a rise in collector voltage which is coupled to the base of Q_2, aiding the forward bias on Q_2.

This regeneration continues until Q_1 cuts off and Q_2 saturates. When Q_1 cuts off, C_1 no longer couples a positive signal to the base of Q_2. C_2 starts to discharge through R_2 at a rate equal to R_2-C_2. When C_2 is sufficiently discharged to remove the reverse bias on the base of Q_1, the transistor again starts to conduct.

This action will continue as long as the power supply voltage is present; the discharge of C_1 controlling the time that Q_2 remains cut off and C_2 controlling the time that Q_1 is cut off. In this manner, C_1 and C_2 control the width of the output pulses.

While we explained the various things happening that caused one transistor to switch from saturation to cutoff, you might have thought this action takes quite some time. Actually, the switching action is very fast. For example, with Q_1 conducting and Q_2 cut off, once the reverse bias on Q_2 disappears and Q_2 begins conduction, current rises to saturation in Q_2, and Q_1 is cut off almost instantly. The result is the output from the multivibrator is essentially a square wave. The square wave output is taken from the collector of Q_2 through C_3. A second output, reversed in phase, is available at the collector of Q_1.

The output of the multivibrator will be symmetrical, that is the two half cycles will be the same if the time constant of C_1 and R_3 is equal to the time constant of C_2 and R_2. However, if we change the time constant of either R-C circuit, the output will no longer be symmetrical. In other words, if we shorten the time constant of the C_1-R_3 network by reducing the value of C_1, it will take C_1 less time to discharge through R_3. As a result, Q_2 will be cut off for a shorter period than Q_1 and the two halves of the square wave will no longer be equal.

There are two major variations of the astable multivibrator, the monostable and the bistable. The bistable is a modification of the astable and can be used as a switching circuit. Basically it is the same circuit as the astable but provision has been made to control the change of the condition of the transistors with an input signal. Upon receipt of an input the transistors in the bistable multivibrator will change state and remain in their new condition until another input pulse is received.

The monostable multivibrator, like the bistable, is a modified astable circuit. Monostable multivibrators have only one stable state and the transistors remain in their respective states (saturated and cut off) until an input pulse is received. At that time the transistors change states and remain in their new state a length of time determined by the R-C components in the circuit. At the end of this R-C time they return to their stable condition.

THE BLOCKING OSCILLATOR

Blocking oscillators are a type of oscillator used for generating pulse waveforms of short time duration followed by a period of no output. Similar to multivibrators, blocking oscillators may be either free running or driven. Let's first look at a free running blocking oscillator, then we will examine a practical application of the circuit.

Fig. 35 shows the basic free-running blocking oscillator. Transformer T_1 provides the necessary regenerative feedback from the collector to the base of Q_1. Terminals 1 and 2 are the primary winding and connect the collector to the power supply. Terminals 3 and 4 are the secondary and furnish feedback to the base. The output is taken across the third winding at terminals 5 and 6. Notice the phase inversion between the different windings.

When the power supply is first energized, a small amount of collector current will flow through the primary of T_1. This current flow induces a voltage in the base winding (terminals 3 and 4). The induced voltage causes C_1 to charge through the low forward resistance of the base-to-

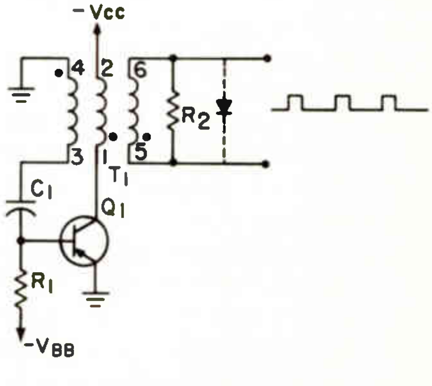

Fig. 35. Free running blocking oscillator.

emitter junction. This couples the induced voltage to the base of Q_1.

Since collector current flow is increasing, the voltage at terminal 1 will be less negative or going in a positive direction. The induced voltage in the base winding is of opposite polarity; therefore, a negative going signal is coupled to the base of Q_1. This increase in forward bias aids collector current and regeneration continues rapidly until the transistor becomes saturated.

When Q_1 reaches saturation, the current is no longer changing; therefore, there is no voltage induced in the base winding. C_1 begins to discharge through the resistor R_1, holding the base-to-emitter junction forward biased. As the charge on C_1 bleeds off, the forward bias on Q_1 decreases.

As the forward bias of Q_1 decreases and collector current is reduced, the magnetic field about the primary winding (terminals 1 and 2) collapses. The collapsing magnetic field induces a voltage in the secondary (terminals 3 and 4) which is positive at terminal 3. This induced voltage, coupled through C_1 drives Q_1 to cutoff.

Due to the reverse bias, Q_1 remains cut off until C_1 discharges through R_1 and T_1 to a point where the base of Q_1 is returned to a forward bias condition. When the forward biased condition is reached, conduction begins and the cycle repeats.

The output pulse width depends mostly on the inductance of T_1. The smaller the inductance, the more rapidly the collector current must increase to maintain a magnetizing current in T_1, the faster the collector current will reach saturation, and the shorter the pulse width. Usually, C_1 has little effect on the pulse width. However, if C_1 is small enough so that the capacitor can charge rapidly during pulse time, there will be a decrease in pulse width.

The frequency of the blocking oscillator in Fig. 35 is determined by the value of R_1-C_1. Compared to R_1, the resistance of the base winding has little effect on the discharge time of C_1.

Resistor R_2 is a damping resistor connected across the output winding of T_1 to reduce the amplitude of the reverse voltage, sometimes called the overswing, caused by the collapsing magnetic field about T_1 at the end of the output pulse. If it were not for R_2, the amplitude of the reverse voltage pulse could exceed the breakdown voltage of Q_1 and damage the transistor. In another type of damping circuit a clamping diode is placed across the collector winding or across the output winding. The diode would then shunt any reverse voltage present in these windings.

Tube type multivibrators and blocking oscillators were once widely used, but in modern equipment they are generally being replaced by transistors. The operation of the older vacuum tube units is essentially the same as the modern transistor units.

Both oscillators with a sine wave output and those with a pulse type output are widely used in communications equipment. Be sure you understand how both types work before leaving this lesson.

SELF-TEST QUESTIONS

(t) In the astable multivibrator shown in Fig. 34, what components control the length of time Q_2 is cut off?

(u) What type output is obtained from the blocking oscillator?

Answers to Self-Test Questions

(a) Regenerative or positive feedback. If positive feedback is not present, oscillations will be damped.

(b) Decrease. Frequency is equal to:

$$\frac{1}{2\pi \sqrt{LC}}$$

Therefore: if inductance increases, the frequency will decrease.

(c) There will be more cycles in the wave train. Losses in the coil of a high Q circuit are low so more cycles occur before the wave train is damped.

(d) .0000005 seconds or .5 microseconds. The formula is:

$$P = 1/F$$

$$P = \frac{1}{2{,}000{,}000}$$

$$P = .0000005 \text{ seconds.}$$

(e) They are in-phase. The voltage developed across L_2 is the feedback voltage and must aid plate current.

(f) The bias voltage developed across R_1. If the oscillator output increased, C_2 would be charged to a higher potential on positive peaks and would produce a larger bias voltage across R_1. The larger bias would reduce the amplitude of the oscillator output.

(g) 1. Oscillator remains energized at all times.
2. Oscillator coil and capacitor are placed in an oven.
3. Temperature compensating capacitors are placed across the tank.

(h) A swamping capacitor is placed across collector-to-emitter junction.

(i) R_1 and C_2 develop the negative bias. L_2 develops the signal.

(j) It goes positive. The reactance of C_2 is small at the resonant frequency of the tank; therefore, the positive voltage induced in the tank by L_2 (voltage across C_1) is coupled to the grid.

(k) C_1 develops the feedback voltage. It is applied to the base through C_3 and across R_1.

(l) The ultra-audion oscillator is a modification of the Colpitts circuit.

(m) Through the R-C phase shift network in the grid. Each pair of R-C components shift the phase a definite number of degrees. Total shift through all stages must equal 180°.

(n) R_2 and C_2 develop the feedback voltage.

(o) To prevent damage to the crystal.

(p) Frequency is controlled by the crystal, Y_1. At the resonant frequency, Y_1 offers minimum impedance to the feedback voltage. At other frequencies, impedance increases.

(q) A higher frequency can be obtained without the use of frequency multipliers.

(r) 1380 kHz.

(s) The tri-tet oscillator functions as an oscillator and a frequency multiplier.

(t) C_1 and R_3. Q_2 remains cut off until the charge on C_1 leaks off enough for Q_2 to become forward biased.

(u) A pulse output followed by a period of no output.

Lesson Questions

Be sure to number your Answer Sheet C206.

Place your Student Number on every Answer Sheet.

Most students want to know their grades as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of lessons before new ones can reach you.

1. If the operating voltage on an oscillator tube is changed so that the plate resistance of the tube increases, what will happen to the oscillator frequency?

2. When adjusting the capacitance of the tank circuit in a crystal oscillator, what happens to the tank current as oscillations start?

3. What component of the blocking oscillator has the most effect on the output pulse width?

4. For what part of the cycle does current flow through the oscillator tube in an L-C oscillator circuit?

5. What is the advantage of a frequency synthesizer over the normal local oscillator circuit in a transceiver?

6. What will the frequency be at 65°C of a crystal oscillator using an X-cut crystal that operates at 5250 kHz at 50°C, if the temperature coefficient is −20 Hz per degree centigrade per MHz?

7. What controls the amount of feedback applied to the base of the transistor in a transistor Colpitts oscillator?

8. In a tuned L-C circuit, if capacitance is increased while inductance is held constant, what will happen to the output frequency?

9. How is positive feedback attained in the Wien-bridge oscillator?

10. How is frequency multiplication obtained in the tri-tet oscillator?

Take The Middle Course

Most of us realize the necessity for moderation in eating and drinking, but we often overlook the fact that moderation in all things is essential to happiness.

Consider, for example, the simple matter of opinions. If a man can see only his own opinions, and is unwilling to recognize that other people may also have good ideas, he is opinionated. A man with this fault is often unhappy, because he doesn't get along very well with other people. On the other hand, if a man yields his ideas to another's too readily, he is weak-kneed - and also unhappy.

If you can give and take - if you are open to reason - if you steer a middle course, you will be liked, people will be comfortable in your company, and you will be following one rule of happiness.

Let "moderation in all things" be one of the guiding principles of your life.

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LINEAR RF
POWER AMPLIFIERS

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LINEAR RF POWER AMPLIFIERS

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STUDY SCHEDULE NO. 21

☐ **1. Introduction** . . . . **Pages 1-2**

A brief discussion of why linear amplifiers are used to amplify the modulated signal at the transmitter.

☐ **2. The Class B Linear Amplifier** . . . . **Pages 2-9**

You learn how linearity is achieved and study the requirements for the driver stage and the plate circuit, and the power considerations for a linear class B amplifier.

☐ **3. Adjusting a Linear Amplifier** . . . . **Pages 9-12**

You learn how to interpret meter readings and study step-by-step adjustment procedures.

☐ **4. Variations in Linear Amplifiers** . . . . **Pages 13-20**

You study push-pull, multi-grid and grounded-grid amplifiers, and the high-efficiency Doherty amplifier.

☐ **5. Outphasing Modulation System** . . . . **Pages 21-28**

Here we take up a system of modulation, which by using phase differences, eliminates the necessity of operating the amplifiers following the modulator in a linear manner.

☐ **6. Answer Lesson Questions.**

☐ **7. Start Studying the Next Lesson.**

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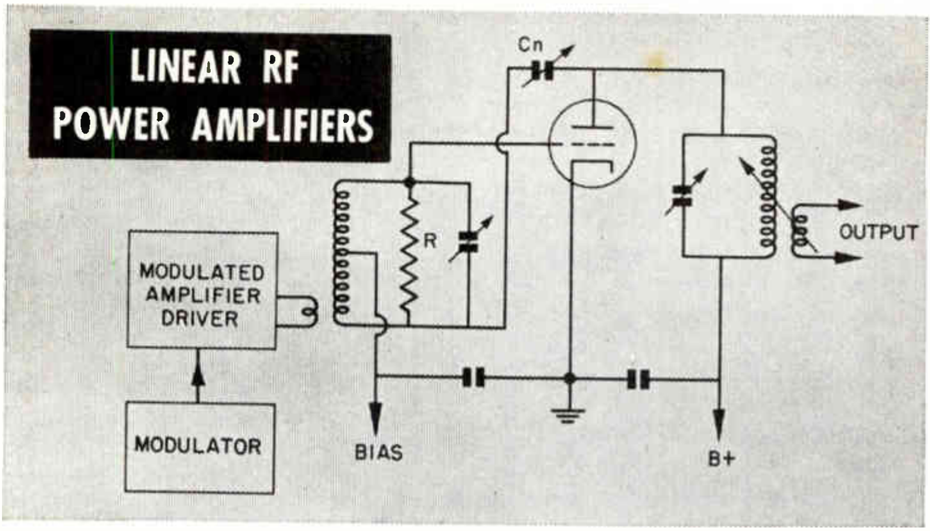
LINEAR RF POWER AMPLIFIERS



As you have learned, in amplitude modulation, the amplitude of the carrier signal is made to vary according to the amplitude variations of the intelligence signal. In some AM transmitters, the modulation takes place in the plate circuit of the final power amplifier stage where the power level is high, so the modulated signal is fed directly to the transmitting antenna. This is called "high-level" modulation. The modulation can also take place in an intermediate class C power amplifier stage. Then, the power of the modulated signal is increased by additional power amplifiers. This is called "low-level" modulation, because it takes place at a lower power level. The modulated signal must not be distorted by stages following the modulated stage. The signal that is fed to the transmitting antenna must be a faithful copy of the output signal from the modulator, or the demodulated signal from the receiver will also be distorted.

The stages that amplify the modulated signal cannot be operated in class C, because a class C stage is driven to saturation at the peak of each positive alternation of the input signal, which would distort the modulated signal waveform. They could be operated in class A, in which case, the output signal would be an exact duplicate of the input signal. However, we want high power output from a transmitter as well as an undistorted signal. A stage operated in class A has very low efficiency and very low power output.

It is most satisfactory to operate the power-amplifier stages following the modulated stage in class B. This gives an undistorted output signal, and more power output than for class A. The class B amplifier stage is operated on the straightest part of its transfer characteristic curve, so that there is a linear relationship between the amplified output voltage and the exciting voltage applied to the input. That is, the output voltage developed across the load is proportional to the grid voltage. An increase or decrease in the excitation voltage will produce a corresponding increase or decrease in the output voltage.

As you will learn in the following section, linearity is obtained by proper adjustment of the grid bias and the load impedance. All the stages following the modulated stage must be operated as class B linear amplifiers.

There is an exception to this, and that is in a system of modulation called "outphasing modulation." With this system of modulation, the rf power amplifiers following the modulator do not need to be linear. You will see why in the last section of the lesson.

First, you will find out how high-power linear amplifiers work, how they are adjusted, and what their advantages and disadvantages are. One of the chief disadvantages of the class B linear amplifier is that its efficiency is lower than that of a class C amplifier. However, it is possible to get higher efficiency by redesigning the stage. An example of a high-efficiency amplifier is the Doherty linear amplifier, which we will discuss.

Linearity in a transmitter can be improved by using feedback between the final linear amplifier output and the speech amplifier section. Feedback will also reduce distortion and improve frequency response and stability in the transmitter stages. We will also take up feedback circuits. First let us find out how the class B linear amplifier works.

The Class B Linear Amplifier

A schematic diagram of a class B linear amplifier stage is shown in Fig. 1. This stage has tuned resonant circuits in the input and output, and is neutralized in the same way as a class C power amplifier.

The basic difference is that the linear amplifier is biased as a class B stage. The tube, however, is not biased exactly to plate-current cut-off. The transfer characteristic curve of a vacuum tube is shown in Fig. 2. Notice that the lower end of the curve bends and is very non-linear before the plate-current cut-off point is reached. If the stage were biased exactly at cut-off, the non-linearity in this part of the curve would cause the signal to be distorted. Therefore, the bias is set a little above the actual cut-off point on the curve, so that the tube will operate only on the straight or linear part. This point is called "extended cut-off," and is shown in Fig. 2. The extended "cut-off" point is found by extending the straight part of the transfer curve until it crosses the current axis. This is the point at which plate-current cut-off would occur if the lower end of the curve were linear.

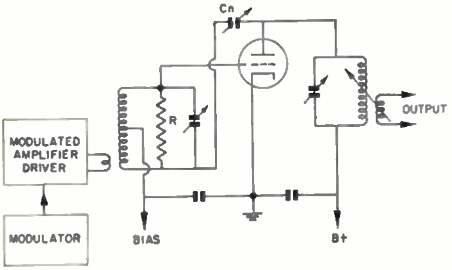


FIG. 1. Basic class B linear amplifier system.

With the grid bias set to the extended cut-off point, the plate current flows for slightly more than 180° of the input signal cycle. In class C, as you learned, the plate current flows for 120° to 150° of the cycle.

The linear power amplifier can be operated in class AB$_1$ or class AB$_2$ instead of in class B. You will remember that a class AB stage is a stage that is biased between class A and class B conditions. In class AB$_1$ operation, the input signal never

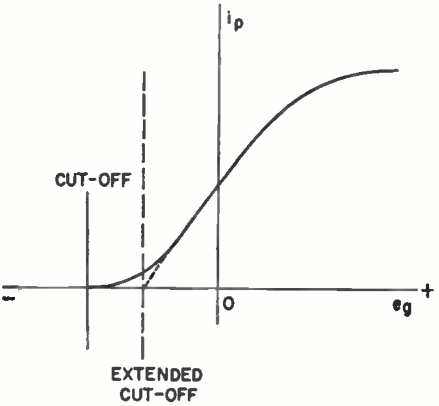


FIG. 2. A tube's e_g-i_p curve, showing the extended cut-off point.

drives the grid positive. In class AB_2 operation, the signal voltage on the grid drives the grid slightly positive on a part of the positive cycle. Class AB_2 operation delivers more power than class AB_1 but less power than class B.

The operation of the linear amplifier can be demonstrated by using the waveform illustrations in Fig. 3. With the grid bias set at the extended cut-off point, a small plate current will flow when no excitation is applied to the input. When a signal is applied to the grid, on the negative alternations the grid is driven below plate current cut-off, so no plate current flows. On the positive alternations, the input signal voltage subtracts from the grid bias, reducing the negative bias on the tube, and the plate current flows for slightly more than the entire positive half cycle. The plate current is in the form of pulses as shown in the diagram.

For distortionless output, the amplifier must operate over the straight portion of the characteristic curve. In other words, the highest peak grid voltage must not swing the plate current beyond point A. As you have learned, on 100% modulation, the

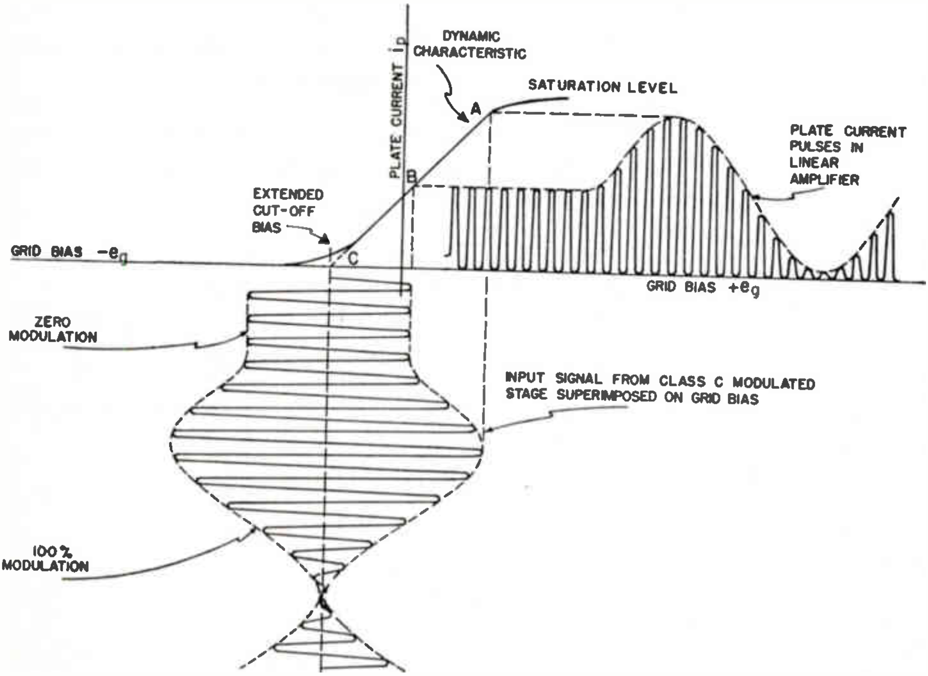


FIG. 3. Class B operation of an amplifier.

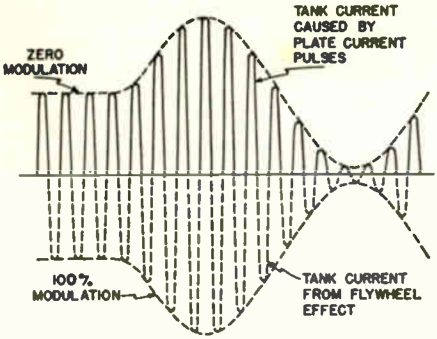


FIG. 4. The flywheel effect of the plate tank circuit in a class B amplifier supplies the missing half-cycles of plate current.

peaks are twice the unmodulated carrier value. In the diagram, the current value at point B is slightly more than half the current value at point A. Thus, if the unmodulated carrier excitation is set at point B, the positive peak at 100% modulation will swing the rf excitation to point A. During the modulation troughs when the modulation amplitude is least, the plate current will be driven near point C. For most efficient linear operation of the amplifier, the grid bias must be set properly so that point B is midway between points A and C, and the input signal must have a high enough amplitude to swing the plate current over the entire linear portion of the characteristic curve between points A and C.

The plate current pulses supply energy to the plate tank on the positive half cycles, just as in a class C amplifier. Then, on the negative half cycles when the plate current is cut off, the energy stored in the tank is fed back into the circuit to form the negative alternations of the output signal. This is shown in Fig. 4. The upper half of the output signal waveform, shown in solid lines, is the part contributed by the plate current pulses. The lower half, produced by the energy-storing (flywheel) action of the tank circuit is shown in dashed lines.

Thus, the output signal fed to the antenna or load circuit is a completely modulated signal, even though the class B rf amplifier tube feeds power to the load for only half of the input signal cycle.

The circuit shown in Fig. 1 is a single-ended stage. In your study of audio stages, you learned that for audio frequencies a class B stage must be operated in push-pull, or the sound will be highly distorted and contain many harmonics. However, this is not true at rf frequencies; a class B stage using a resonant circuit in the plate circuit can be single-ended because the resonant circuit restores the missing parts of the modulated signal wave-form. The resonant circuit also eliminates many of the undesired harmonics.

HOW LINEARITY IS ACHIEVED

The proper operation of a class B linear stage is determined by its grid bias, grid drive, plate voltage, load impedance, plate and grid currents, and the power relationships in the

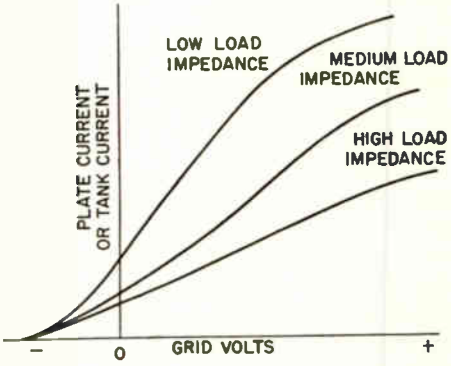


FIG. 5. Linearity curves for a class B amplifier using various values of load impedance.

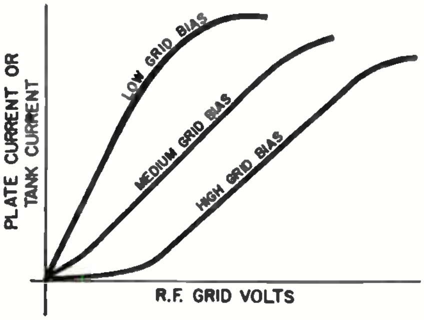


FIG. 6. The effect of various grid bias values upon the linearity of a class B amplifier.

input and output circuits. The linearity in the stage depends primarily on the grid bias and the load impedance.

The plate load impedance must be chosen to get high power output and efficiency as well as good linearity.

Load Impedance. Fig. 5 shows the effect of various load impedances on a tube operating in class B. The instantaneous grid voltage, made up of the bias voltage and the rf excitation signal, is plotted along the horizontal axis. The plate current, or proportional tank current, is plotted along the vertical axis. As you can see, the curve is not linear for low impedance but is quite linear for high impedance. The low impedance is not satisfactory, because the output would be distorted, although it is ideal for class C operation because it has high power output. The high impedance is not satisfactory either, because the plate current swing would be small and the power output very low.

Proper loading of a linear amplifier must be a compromise between linearity and power output. The medium load impedance curve in Fig. 5 is the one that is usually chosen. For a triode tube, the best value of the load impedance is equal to about twice the plate resistance of the tube.

Grid Bias. Now let us see how the grid bias affects the linearity of the stage. Fig. 6 shows the dynamic characteristic curves for various values of grid bias. With a low grid bias, the lower part of the curve is linear, but it soon folds over. If a modulated signal were applied to the input, the peak of the modulation envelope would be compressed, and the signal would be distorted.

With high grid bias, the curve is flat or compressed at the bottom, and a modulated signal would again be distorted. A medium value of bias is best for linear operation. There is a slight bend near the bottom of the medium bias curve which is kept at a minimum by operating the tube at the extended cut-off bias as discussed previously.

The grid bias for the linear amplifier must be supplied from a separate low-impedance power supply. Grid-leak bias, which is used in class C stages, cannot be used in a class B linear stage, because the excitation to the linear amplifier is not constant; the grid current flow is small for low modulation and very high for 100% modulation. Thus, the grid-leak bias itself would vary over the modulation cycle and cause distortion.

Sometimes a cathode bias resistor is used, because the average cathode current in a linear amplifier is constant and does not vary during the modulation cycle. However, a cathode bias resistor wastes too much power for use in a stage other than a low power stage, so fixed bias is more often used.

The power supply that provides the bias voltage must be a low-impedance supply, because if the impedance is low, the variation in the grid current due to the input signal will have little effect on the dc bias voltage. Also, by using a separate bias source, the bias can be easily adjusted to get the exact value required for the most linear operation of the stage.

Excitation. The excitation must be carefully set to prevent distortion during modulation peaks, because regardless of what load impedance or grid bias is used, an excessive grid excitation will cause the plate current to swing into the curved portion of the characteristic curve. At the same time, the excitation must be high enough to operate the class B stage with reasonable efficiency. Thus, the driver stage must be operated properly to get undistorted linear output.

REQUIREMENTS OF THE DRIVER STAGE

Now let's consider the requirements of the stage that drives the class B amplifier. Because grid current flows in the class B amplifier during the part of the cycle that the grid is driven positive, power is being dissipated in the grid circuit. This power must be supplied by the driver stage. The higher the grid current, the lower the impedance presented by the amplifier, and the more power the driver stage must supply.

During an rf cycle, the grid impedance of the amplifier may change from an infinite value for negative grid potential to only a few hundred ohms for a high positive potential. This varying impedance places a varying load on the driver with the result that the driver output voltage, which is fed to the amplifier to drive it, will vary. For no grid current and a light load, the driver voltage will be high; for high grid current and a heavy load, the driver voltage will be reduced. If the output impedance of the driver is too high, this effect becomes worse and the driver output voltage may become so low when the amplifier grid is drawing current, that the grid is not driven far enough positive to drive the stage.

The positive peaks of excitation will be flattened out as shown in Fig. 7. When this happens, we say the driver has poor regulation. In Fig. 7, the excitation of the grid of the class B amplifier from a poorly regulated driver is shown in heavy lines. For comparison, a perfect sinusoidal excitation voltage is shown in dashed lines. Obviously, even though the amplifier is operating over a perfectly linear dynamic characteristic curve, excitation such as that in Fig. 7 will cause serious distortion.

To minimize this grid-loading effect, the driver regulation must be made as good as possible. This is usually done by designing the driver stage so that it is capable of delivering two or three times as much power as that required to drive the grid of the amplifier. This keeps the impedance of the driver down. In addition, the input tank of the amplifier is shunted by a relatively low resistance. This resistance, shown as R in Fig. 1, absorbs considerable driver power, but reduces the wide fluctuations in grid circuit impedance. With this resistor, the input circuit impedance can change from a few hundred ohms only up to the value of the shunting resistance. Thus, the driver works into a more nearly constant load.

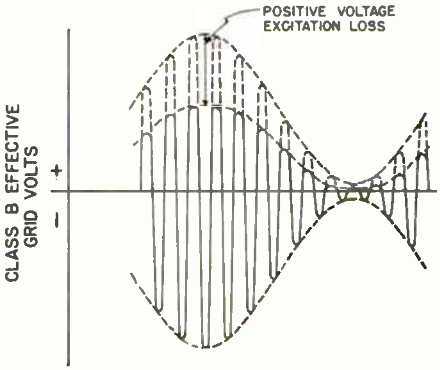


FIG. 7. How poor voltage regulation of the driver stage causes distortion of the class B amplifier excitation.

The grid-loading resistor may not be required if a special zero-bias tube is used in the class B stage. The operating bias for these tubes is very low, usually from 5 to 10 volts. The grid loads the circuit at all times, during the positive half of the input cycle so the impedance remains nearly constant during this half of the cycle. Since this is the only half of the input cycle we are interested in, it does not matter that the impedance changes during the negative half cycle.

Another way of assuring proper drive to the linear amplifier is to operate the amplifier as a class AB amplifier. If the amplifier is operated in class AB_1, the grid is not driven positive, so no grid current flows. The grid circuit impedance remains constant, and furthermore the driver needs to supply only an exciting voltage—it does not have to supply any power because no grid current flows.

Since the efficiency of a class AB_1 stage is low, a compromise arrangement is to operate the stage as a class AB_2 amplifier. Here the grid is driven positive during only part of the positive half cycle, and the power requirements are less than for class B operation. This enables us to get better driver regulation and hence a more linear output. Some modern linear amplifiers using tetrode tubes are operated as class AB amplifiers, usually class AB_2. Reasonably good efficiency can be obtained from these stages and the driving power requirements are low. Good efficiency can be obtained from class AB_2 tetrode stages because tetrode tubes have a high power sensitivity, that is, they can develop a high power output in the plate circuit with a low power input in the grid circuit.

PLATE CIRCUIT REQUIREMENTS

As in class C operation, the plate voltage in a class B or class AB linear amplifier has a decided influence on the power output. It must be high enough for maximum linear output without causing excessive plate dissipation. Naturally, the maximum rf peak voltage that can be developed across the load impedance is somewhat less than the B supply voltage.

With 100% modulation, during the negative half of the cycle of the rf exciting voltage, the tube is driven beyond cut-off, and the voltage developed across the load impedance is equal to the B supply voltage. During the positive half of the input cycle, when the tube is driven up close to the saturation point, maximum plate current flows, the tube plate resistance drops to a low value, and the plate voltage is very low. The maximum change in plate voltage is between this low value and the actual value of the B supply voltage. This maximum change occurs only during 100% modulation; for lower percentages of modulation, the plate voltage change is not as great.

The changes in the grid excitation voltage and in the output voltage are linear. In other words, a variation in the rf voltage applied to the grid will cause a corresponding variation in the plate voltage. This linear relationship depends upon the grid bias value. In a class C stage, the plate is driven to saturation in order to get a higher plate efficiency. In the saturation region, the excitation voltage and the plate voltage are no longer linear. To avoid the distortion that would result from this non-linearity, a linear amplifier is never driven into the saturation region.

If the amplifier has a truly linear characteristic, the plate current increase during the modulation crest is equal to the plate current decline during the trough. Hence, the average plate current read on a dc plate current meter is constant and should not change from no-modulation to 100% modulation. The average plate current will be equal to the peak plate current with no modulation when a linear amplifier is used to amplify a carrier and two modulation sidebands. In a later lesson you will see that in some applications of linear amplifiers the plate current does change with modulation.

POWER CONSIDERATIONS

In an earlier lesson you learned that the output power from a class C stage is proportional to the square of the plate voltage; in other words, if you double the plate voltage, the output power will increase four times. This relationship exists because the signal applied to the grid drives the tube from cut-off all the way to plate current saturation on every cycle. In a class B or a class AB linear amplifier, the output power is proportional to the square of the *exciting signal voltage*. With a constant load resistance, if the input signal voltage is doubled, the output power will increase four times because both the signal voltage and signal current developed in the output will double. Thus, the input signal has direct control over the output power.

The linear amplifier has a constant plate voltage and, when operating correctly, functions with a constant average plate current. Hence, it draws a constant amount of power from the high-voltage supply.

In your study of amplitude modulation, you learned that with 100% modulation, at the peak of the modulation the power of the carrier is four times the power without modulation. You have also learned that the plate input power of a linear stage remains constant whether or not modulation is applied. Therefore, the amplifier must have higher efficiency during modulation. (The higher the efficiency of an amplifier, the higher the power output.) When the stage is fed with an unmodulated carrier, its efficiency is 30% to 35%. For full 100% modulation its efficiency increases to 60% to 70%. The plate input power divides between the tube and the output load. With no modulation, two-thirds of the input power must be dissipated by the tube plate; at 100% modulation, only one-third must be dissipated by the tube plate. This shows that the linear amplifier tube runs cooler when it is delivering the most power output (high modulation percentage).

Since the modulation peaks of speech and music are often 10 to 20 times as great as the average signal level, the average grid excitation must be kept low. The average efficiency of a typical linear amplifier is usually not over 40%.

The power gain, which is the ratio of the output power to the driving power, of a linear amplifier is usually between 5 and 10 with triode tubes, and between 20 and 50 with tetrode and pentode tubes. The gain is low when triode tubes are used because triode tubes require a substantial driving power because of their low power sensitivity and also because the losses in the grid circuit are often quite high.

If a stage has a power sensitivity of 10, we will need a driving power equal to 1/10 of the power output. For example, if the power output of a linear amplifier with no modulation is 10 kw (10,000 watts) and the stage has a power sensitivity of 10, the driving power needed would be 10 kw ÷ 10 = 1 kw. If the efficiency of the linear amplifier is 33 1/3%, the input power to the stage would be 30 kw; 10 kw would be useful output and the other 20 kw would be dissipated as heat by the tube. If the driver is a plate-modulated class C amplifier with an efficiency of

66 2/3%, the plate input to the driver would be 1.5 kw (1500 watts). To plate modulate the driver we would need approximately 750 watts of audio power. Thus, we can 100% modulate the 10 kw output of the linear amplifier with only 750 watts of audio power.

On the other hand, if we tried to plate modulate an amplifier with an output of 10 kw we would need much more audio power. If the efficiency of the stage is 66 2/3% (a class C stage), the power input would be 15 kw and to 100% modulate the stage would require 7.5 kw of audio power. This is ten times the power needed for 100% modulation when we modulated the driver and operated the power output stage as a linear amplifier. Thus, the poor efficiency of the linear amplifier is compensated for by the lower audio power needed for 100% modulation. In high-power transmitters it is more economical to modulate one of the low power driver stages and then amplify the signal with linear amplifiers than it is to try to plate modulate a high power class C amplifier.

Adjusting a Linear Amplifier

Fig. 8 shows the schematic diagram of a typical single-ended class B linear stage. Notice the similarity between this circuit and the conventional class C amplifier stage. The plate and grid resonant circuits and neutralizing method are identical to those used for class C. The modulated rf signal is link-coupled to the grid of the amplifier from the plate circuit of the modulated stage. Thus, the modulated stage acts as the driver.

Resistor R1 connected across tuning capacitor C2 and part of coil L2 is the grid-loading resistor. It is used to prevent wide impedance variations

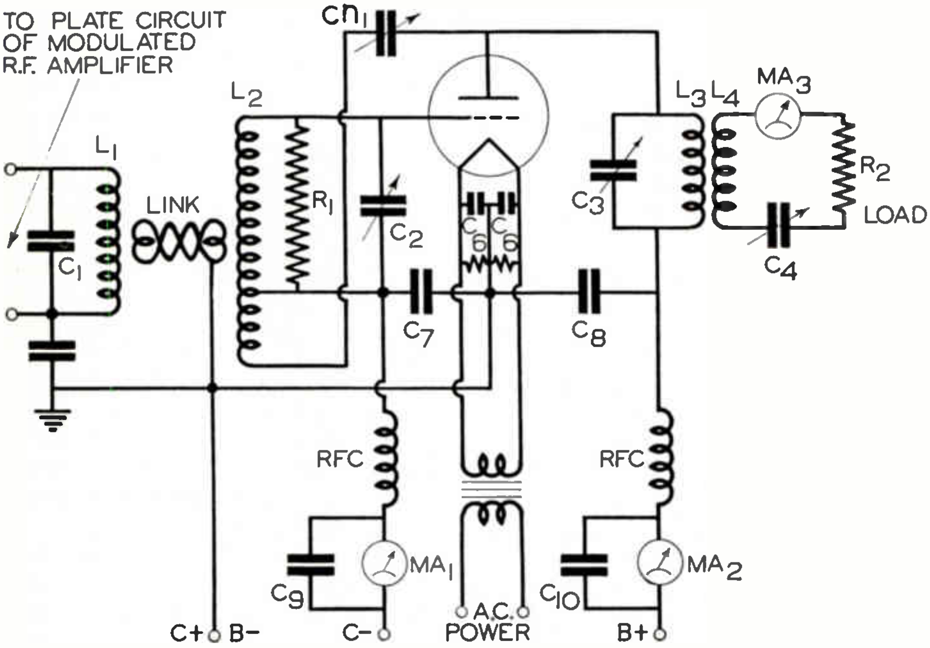


FIG. 8. A typical single-ended class B linear rf amplifier.

in the amplifier grid circuit, and thus present a more constant load to the driver stage. The bias voltage for the grid is obtained from a separate low-impedance supply.

As shown in Fig. 8 there are current meters in the circuit to indicate the operation of the amplifier. Meter MA_1 indicates the grid current, meter MA_2 indicates the plate current, and meter MA_3 indicates the load current. The meters in the grid and plate circuit are shunted by capacitors to prevent rf currents from damaging them.

INTERPRETING METER READINGS

From the readings on the grid current, plate current, and output current meters you can determine whether or not the amplifier is operating correctly. If the amplifier has been adjusted correctly and is being driven by a well regulated driver, the meter readings should be as follows:

With no modulation on the carrier, the grid current will be small and steady. The plate current will also be constant and its value should be that recommended for the rated power output. The reading on an antenna current meter should be constant. Its exact value of course will depend on the power output of the stage, the type of transmission line used to connect the amplifier to the load, and on how well the line is matched to the load. For the present, all you need be concerned about is that with no modulation the meter reading should be constant.

On 100% sine-wave modulation, the grid current reading should rise sharply to a maximum value. The plate current, however, should not change and will not if the amplifier is truly linear. Any change in the plate current reading is an indication of nonlinearity. The output load current in MA_3 should increase 22.5% with 100% sine-wave modulation.

With voice or music modulation, the grid current reading will rise and fall with the peaks of the modulation. The antenna current meter will also fluctuate, but the plate current should never vary from its normal steady reading.

Since the average power contained in voice and music is low, the antenna or load current will rise only a few percent higher than with no modulation. There will be a sharp rise in the load current value only on loud sustained passages.

The grid, plate, and output meter readings can also be used to localize defects and causes of distortion. The modulated signal fed to the linear amplifier stage must be free from distortion. Therefore, when checking any linear amplifier circuit, almost the first test to make is to see that the input signal itself is linear and undistorted. If it is distorted, check the modulated amplifier and the modulator stages. Be sure that their operating voltages and drive are correct, that the class C amplifier is not being over-modulated, and that the tuning and loading are correct for the stages.

If the input signal is not distorted, incorrect meter readings may indicate defects in the linear amplifier itself. Suppose the plate current reading increases and the pointer on the antenna current meter "kicks up" sharply when modulation is applied. A rise in antenna current is normal; the meter pointer, however, should not swing up or down sharply. (You may not notice abrupt changes in meter readings if a thermocouple meter is used.) This indicates a positive carrier shift (upward modulation). The plate and antenna current increase can be due to excess bias on the grid, which causes the tube to operate further down on the knee of the characteristic curve. This will cut off the trough of the modulated signal, causing the average plate current to rise. Parasitic oscillations, incomplete neutralization of the amplifier, and improper tuning and loading of the stage can also cause positive carrier shift.

Negative carrier shift (downward modulation) occurs when the average plate current and the antenna (output) current decrease with modulation. This is due to a defect that cuts off or distorts the peaks of the modulated signal. If an excess amount of excitation is applied to the grid, the tube will be driven to saturation, and the positive peaks will be distorted. Poor regulation in the bias or high-voltage power supplies can also cause negative carrier shift because the grid or plate voltages are not high enough to provide the peak values of the amplified waveform.

Also, if the load that the linear amplifier presents to the driver stage varies widely during the input signal cycle, the peaks of the modulated waveform at high modulation levels will be cut off. The output signal will be distorted, as indicated by a decrease in the antenna meter reading. The purpose of the shunt resistor across the coil in the grid circuit is to prevent the load on the driver stage from varying. A higher than normal load impedance for the class B linear stage or incorrect tank circuit tuning will also cause the modulation peaks to be cut off, and cause the readings on the plate and antenna current meters to decrease.

A decrease in the grid and plate current meter readings over a period of time could indicate a loss of efficiency in the driver amplifier or some defect earlier in the transmitter, causing a loss of excitation power to the linear amplifier. Also, a gradual decrease in the grid and plate current meter readings is often an indication of a weakening linear amplifier tube.

Thus, to get an undistorted output signal from a class B linear amplifier stage, the operating voltages, grid drive, and loading must be correct. Also, the stages preceding the linear amplifier must be operating properly to produce an undistorted signal of the correct amplitude to the stage. Usually the recommended operating voltages are applied to the stage and then the grid bias and the load are varied slightly on either side of the recommended values to get the greatest undistorted power output at the best efficiency. This is a part of the adjustment procedure; let us go through the complete procedure now.

ADJUSTMENT PROCEDURES

Before the class B stage itself can be adjusted, the preceding stage must be adjusted, and the class C modulated stage and the class B stage itself must be neutralized. During adjustment the grid bias and plate voltages are not set to their full final values to be sure tubes and other parts are not damaged, and to prevent the possibility of interfering with other broadcast stations. The procedure for adjusting a class B stage using triode tubes is as follows:

1. Apply grid bias of one-half its final intended value.
2. Apply a low-amplitude unmodulated rf signal to the input.
3. Increase the level of the unmodulated rf signal by tightening the coupling between the driver and the amplifier until there is grid current flow.
4. Readjust the plate tank circuit of the driver stage, and the grid tank circuit of the amplifier stage to resonance by tuning each for maximum grid current.
5. Apply plate voltage of one-half the final intended amplitude.
6. Quickly tune the plate tank to resonance as indicated by a dip to

minimum in the plate current.

7. Couple the load circuit to the amplifier by increasing the coupling between the output tank circuit and the coupling network to the antenna or the next stage; as coupling is increased, readjust the tank capacitor to resonance. Continue increasing the coupling until the plate current minimum is approximately three times the minimum without a load.

8. Apply normal plate voltage and extended cut-off grid bias to the stage.

9. Check the plate current and the output current readings. If they are both too high, reduce the excitation to the stage. If the plate current is high and the output current is low, reduce the excitation and increase the load coupling; then, increase the excitation again. If the plate current is still too high, the grid bias may be too low. In this case, to get the best possible linearity, it may be necessary to vary the bias slightly above or below the value recommended by the transmitter manufacturer.

If you get good linearity for a bias voltage near the recommended value, and the input and output power are correct with full excitation, the amplifier is properly adjusted.

If the plate current is still too high or the plate input power and the output power are below normal, the load impedance is too high. Readjust the load coupling and make a new set of linearity checks.

10. Make a final check of all meter readings with modulation applied. The grid current meter reading should change rapidly with modulation, and the plate current meter should remain steady. The load current meter reading will increase very slightly with normal modulation. However, with sustained 100% sine-wave modulation, the load current reading should rise 22.5%.

You can also use an oscilloscope to check the linearity of a linear amplifier system. To do so, you first observe the modulation envelope at the output of the driver to make certain that an undistorted signal is being applied to the linear amplifier. Then, you use the oscilloscope to check the performance of the linear amplifier itself, with 100% sinusoidal modulation applied. The major advantages of oscilloscopic checks are that they are instantaneous and do not require a tedious step-by-step measurement procedure. The oscilloscope can be used to monitor the output of the transmitter during normal operation, to provide an immediate indication of any non-linearity. You will receive detailed instructions on how to use the oscilloscope in a later lesson.

The adjustment procedure for a class B linear amplifier using pentode or tetrode tubes is the same as for triode tubes, except that some load should be connected to the stage before plate and screen voltages are applied to the stage. If you attempt to tune a pentode or tetrode rf stage without a load connected to it you may destroy the tube.

Variations in Linear Amplifiers

So far, we have been discussing single-ended linear amplifiers. Linear amplifiers may also be operated in push-pull and can use multi-grid tubes as well as triodes. There are differences in the operation of single-ended and push-pull stages, but the basic characteristics and the purposes for which they are designed are the same. We will show several examples.

PUSH-PULL LINEAR AMPLIFIERS

A class B push-pull stage using triode tubes is shown in Fig. 9. Resistors R1 and R2 load the grid and establish proper driver regulation. The two radio-frequency chokes shunting the loading resistors provide low resistance dc paths for the grid current so there will not be any unwanted grid-leak bias. Regular push-pull cross neutralization is used, and the metering arrangements are similar to those for a single-ended stage.

Advantages. The push-pull class B linear amplifier in Fig. 9 has some advantages over the single-ended type. Twice as much power can be obtained from a push-pull stage, and the Q of the tank circuit can be lower than in a single-ended stage, if the push-pull tubes are properly balanced. The Q of the tank circuit of the single-ended stage must be higher, because the single-ended class B stage depends upon flywheel effect in its plate tank circuit to establish one alternation of the rf output cycle. If the Q is too low, the flywheel effect is inadequate and the modulation envelope is distorted. This means that the second harmonic content becomes high and filters must be used to reduce second harmonic radiation. Hence, a compromise must be made in a single-ended stage between power output (which depends on the circuit loading) and the tank circuit Q.

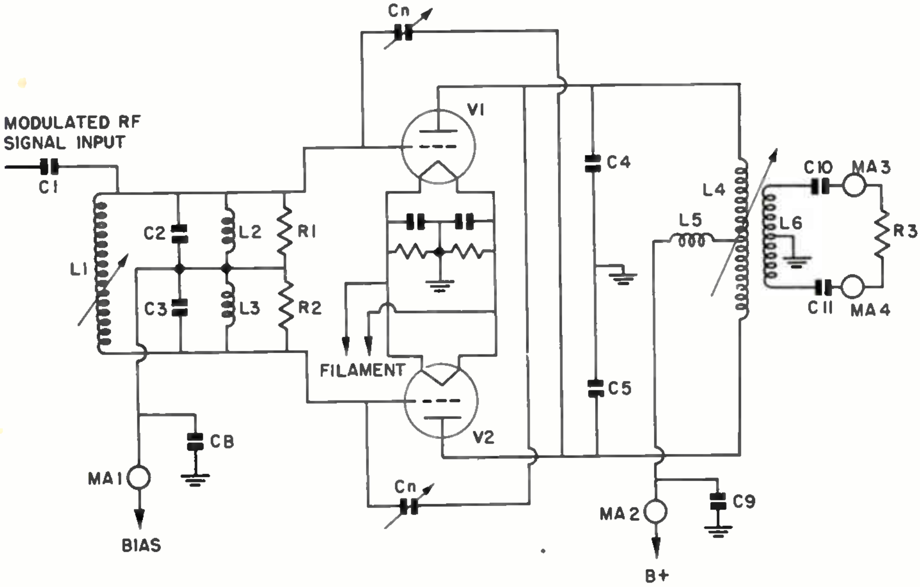


FIG. 9. Push-pull class B linear amplifier.

In a push-pull class B stage, one tube supplies energy during the positive half-cycle. Its plate current then falls to zero, and the other tube supplies energy for the negative half-cycle. Consequently, each tube contributes one-half or 180° of the complete rf cycle. Since the tubes supply energy to the tank circuit for the entire signal cycle, the tank circuit flywheel effect is not essential. The load can be coupled into the tank circuit for optimum power output and efficiency and for the best linearity. Thus, the power output is higher and the harmonic distortion is less for push-pull class B operation.

The circuit Q is still important in a push-pull stage. A low Q tank circuit will pass a considerable amount of harmonics, but by balancing the tubes properly, much of the even-harmonic energy can be eliminated. A low Q circuit will reduce the tank circuit losses and raise the efficiency. In a high power transmitter even a 5% loss in output power is a considerable amount, when it just heats the coil.

There is also less sideband clipping in a push-pull stage than in a single-ended stage. In a single-ended stage, to maintain an adequate flywheel effect, the Q of the tank circuit must be quite high and sharp. Thus, some of the higher frequency sidebands may be clipped off. With push-pull operation, the Q can be considerably less, and therefore, the tank circuit response is broad and sideband clipping is less likely to occur.

The load impedance in the push-pull stage must be chosen correctly to get the best linearity, power output, and efficiency. For a stage using triode tubes, the load impedance is about twice the plate resistance of one of the amplifier tubes. This is considerably less than the load impedance required for a push-pull class B audio amplifier in which the load impedance is four times the plate resistance of one of the tubes.

Adjustments. The adjustment procedure for the push-pull class B linear stage is similar to that described for the single-ended stage. The preliminary adjustments are made, as described previously, and then the grid and plate voltages are set to half their normal values. After the class B stage adjustments are completed, full normal operating voltages are applied. Usually small touch-up adjustments are required for best operation.

LINEAR AMPLIFIERS USING MULTI-GRID TUBES

Tetrode, pentode, and beam-power tubes are also used in linear amplifiers. Multi-grid tubes give better power gain, and less driving excitation is required for a given power output. Also, the additional electrodes give better shielding, so neutralization is not as much of a problem.

However, to prevent non-linearity, the voltage applied to the screen grid must be very well regulated. Variations in screen voltage as the modulation changed would have the same effect as variations in grid bias in a triode linear amplifier. Variations in screen voltage would cause the plate current and power output of the amplifier to change in a non-linear manner, causing a distorted modulation envelope. In low-powered amplifiers, it is common to use small voltage-regulator tubes, and in higher-powered amplifiers, the screen voltage is obtained from an extremely well-regulated power supply.

The multi-element tubes are often operated in class AB_1 or AB_2. An advantage of AB_1 operation is that no driving power is needed because the tubes will not draw grid current. Driver regulation is much less of a problem because the grid circuit in-

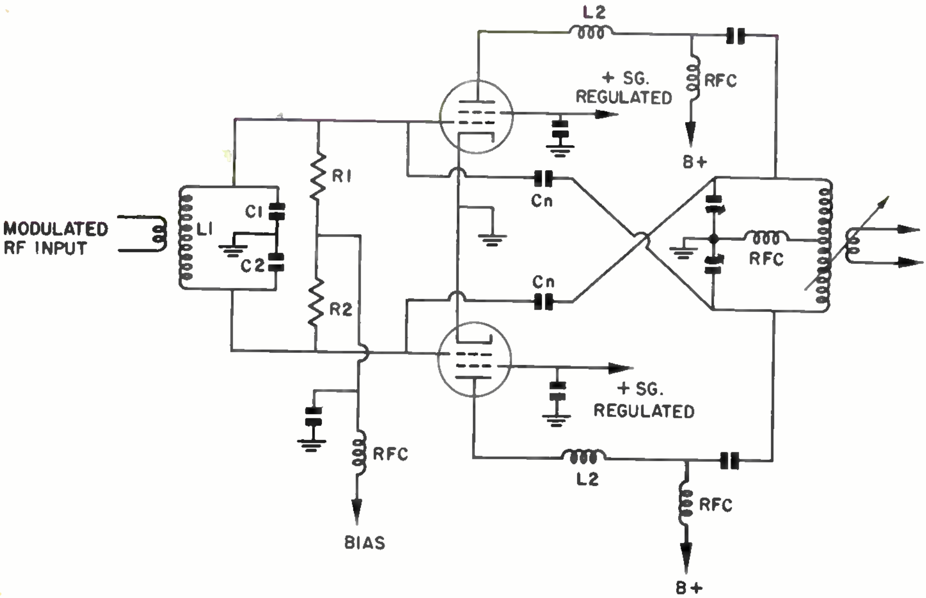


FIG. 10. A class AB_1 linear amplifier using tetrodes.

put impedance does not vary as in a class B linear amplifier, which draws a very high grid current. A class AB_2 amplifier draws some grid current, but not as much as class B.

The class AB_1 linear amplifier may have two tubes in push-pull, or four or eight tubes in a push-pull parallel combination. Fig. 10 shows a linear amplifier with two tubes in push-pull operated in class AB_1. Resistors R1 and R2 in the grid circuit load the input, increase the circuit bandwidth, and broaden the response of the input resonant circuit so that the input does not have to be tuned. Thus, capacitors C1 and C2 can be fixed rather than variable capacitors.

Neutralization of the multi-grid tubes is not exacting, and two small fixed capacitors, such as those labeled C_n in Fig. 10, are often used.

The output circuit has parasitic chokes and a split-stator tuning capacitor, making it similar to most push-pull class C amplifier output circuits. The class AB_1 operation depends upon the loading, biasing, and excitation.

The screen voltage is obtained from a voltage-regulated supply.

GROUNDED-GRID AMPLIFIER

A linear rf amplifier may also use a grounded-grid circuit, as shown in Fig. 11. The grounded-grid circuit gives somewhat better linearity than a grounded-cathode circuit.

The exciting voltage is applied between the cathode and ground. The input of the grounded-grid amplifier presents a low impedance load for the driver. Thus, it is not necessary to

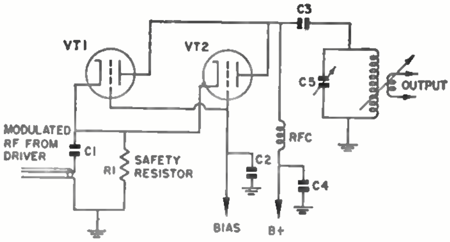


FIG. 11. A grounded-grid linear amplifier.

use a tuned circuit in the input. The driver can be connected directly between the cathode and ground, if a capacitor is used for proper dc isolation between the driver and the linear amplifier. The cathode resistor is inserted to prevent a high voltage from appearing between the cathode and ground in case an open develops between the driver and the cathode circuit of the amplifier.

A grounded-grid amplifier is very stable; much more stable than a conventional grounded-cathode amplifier. The control grid is at rf ground potential and acts as both a control element and a screen between the cathode and plate. Therefore, the stage usually does not have to be neutralized. This stage also operates better at frequencies above 50 mc than the grounded-cathode amplifier does. If it is used at these high frequencies, the inductance of the leads in the input and output circuit and the grid-to-plate capacity can provide enough feedback to cause instability and perhaps oscillation. In this case, the stage must be neutralized.

When filament-type tubes are used, the grounded-grid amplifier requires a special filament transformer that has a very low capacity between the primary and secondary windings. The capacity between the windings will shunt the signal to ground.

The stage requires more power from the driver than does a grounded-cathode stage. This additional power, however, does not represent a loss, because the extra power actually appears in the plate circuit of the stage. Thus, the output power comes partly from the driver and partly from the amplifier itself.

DOHERTY AMPLIFIER

We have learned that the average efficiency of a conventional linear amplifier is seldom better than 40%. With 100% modulation, we can get an efficiency of about 70% on modulation peaks, because then the amplifier is operated near saturation. If we could operate the amplifier near saturation at all times, its efficiency would be high, but then, on modulation peaks, the output would be distorted, because the peaks would be flattened out—the amplifier would not be able to supply the additional power demanded of it on peaks.

It is possible to get an average efficiency of from 60% to 65% by using a two-tube circuit like that shown in Fig. 12. This amplifier is called the Doherty amplifier. The circuit is arranged so that the unmodulated signal from the driver drives

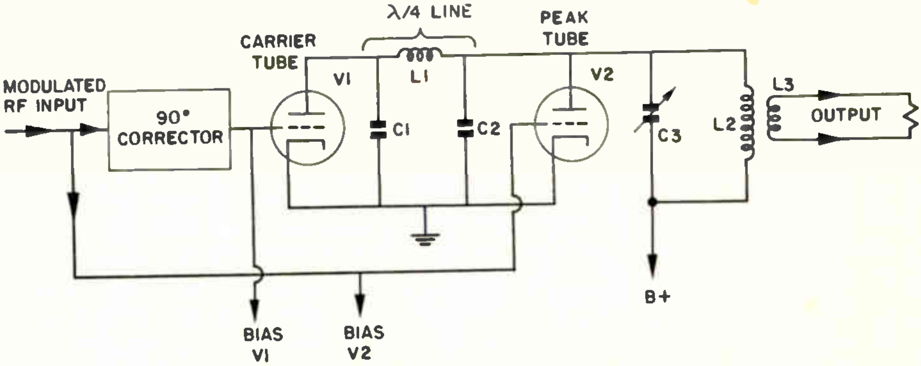


FIG. 12. A basic Doherty system.

one tube, called the carrier tube, to saturation while the other tube, called the peak tube, passes little or no plate current. Thus we have one tube operating at peak efficiency and the other tube wasting little or no power.

The two tubes are of the same types, and therefore will have almost identical characteristics. The carrier tube is biased at the extended cut-off value as a true class B linear amplifier. The peak tube has about twice as much bias applied to it so that it operates more as a class C amplifier than a class B amplifier. When the unmodulated signal from the driver is fed to this tube it barely drives it into the conducting region.

The load on both tubes is the parallel resonant circuit made up of C_3 and L_2 and the load connected to it through L_3. The output of the peak tube, V2, is connected directly to this load. The parallel resonant circuit is designed so that the load impedance will be about half what would normally be used for one of the tubes operated in the normal way as a Class B amplifier. Thus, if the load should be Z_L, the load impedance that V2 will see will be $Z_L/2$.

The load the carrier tube, V1, will see will be quite different. V1 is connected to the load through a network consisting of C_1, L_1, and C_2. This network is called an artificial transmission line because it acts like a transmission line. By selecting the values of C_1, L_1, and C_2, we can make the network act like a transmission line one quarter of a wavelength long. (The symbol λ that you see on the diagram is the Greek letter Lambda, and is used as an abbreviation for wavelength.) You will study transmission lines in detail later; for the present you need know only a few things about them.

Transmission lines have a characteristic which is known as the "surge impedance" or "characteristic impedance." It depends on the size of wire used, the spacing between the wires, and the material between the wires. The characteristic impedance is represented by the symbol Z_o. When a load Z_1 is connected across one end of a quarter-wave line, the impedance that is seen at the other end, which we will call Z_s is given by the formula:

$$Z_s = \frac{Z_o^2}{Z_1}$$

If we make the characteristic impedance of this line equal to the load that the tube should work into for normal class B operation (Z_L), and the actual load equal to half the normal class B load, then the impedance looking into the line from V1 becomes

$$\begin{aligned} Z_s &= \frac{Z_L^2}{\frac{1}{2}Z_L} \\ &= \frac{2Z_L^2}{Z_L} \\ &= 2Z_L \end{aligned}$$

Thus, the load impedance into which V1 is working is equal to twice the normal load for class B operation.

Another characteristic of a transmission line is that it delays a signal traveling through it. With a quarter-wave line between V1 and the load there will be a one-quarter cycle delay. We refer to this as a 90° delay or a 90° phase shift. One other characteristic of a quarter-wave line is that it inverts any change in the load connected across the output. If the impedance of the load is increased, at the input the line acts as if the impedance had been reduced, and if the impedance of the load at the output is reduced, at the input it acts as if it had been increased. Now let's go ahead and see exactly how this amplifier works.

When an unmodulated signal is fed from the driver to the amplifier, the signal does not drive the grid of V2 hard enough to cause this tube to conduct any appreciable amount of plate current. The signal from the driver is fed to the grid of V1 through a phase-shifting network that advances the signal phase so that the signal applied to the grid of V1 leads the signal fed to the grid of V2 by 90°. This signal drives the grid of V1 hard enough to drive this tube to plate-current saturation. Thus the tube operates with good efficiency. However, because the load impedance is twice the normal class B load impedance, the power output will be only about half of what would be obtained with the correct load impedance. The output from V1 is fed through the artificial line, which delays it 90°, to the load. Since the signal has been advanced 90° and then retarded 90°, the two phase shifts cancel, so the signal reaching the load from V1 will be in phase with any signal reaching it from V2.

When the driving signal is modulated and its amplitude starts to increase, V2 begins to conduct. This results in an increase in the signal voltage across the load because the load current increases. The quarter-wave transmission line, which is also connected to the load, sees this higher voltage. Since the extra current is not coming from this line, the higher voltage across the load has the same effect on the line as an increase in load impedance. The quarter-wave transmission line inverts this change so that at its input the impedance decreases. This means that the impedance of the load that V1 is working into goes down, and V1 supplies more power to the load.

With 100% modulation, the amplitude of the driving signal will drive V2 to saturation. Since its load impedance is only ½ the normal value of Z_L, it will supply twice the power it would if it were operated at saturation with the normal load impedance. This power supplied to the load causes the voltage across it to increase so that the value of the load impedance connected at the end of the quarter-wave transmission line appears to have doubled. This means that it is now equal to Z_L. The impedance at the other end of the line, to which V1 is connected, becomes:

$$Z_s = \frac{Z_L^2}{Z_L} = Z_L$$

Therefore V1 is now working into the load impedance it should work into for normal class B operation, and the power output from it will be twice the value with no modulation. Thus both V1 and V2 are supplying twice the power to the load that V1 supplied to it with no modulation, so the power output has increased four times, as it should with 100% modulation.

You might wonder how we can say that the efficiency of this amplifier is good when with no modulation one tube is supplying only half the normal class B power to the load and the other tube none at all. You must remember that efficiency is not a measure of the amount of power output. If the ratio of the power output to the power input is high, the stage is efficient regardless of how much power it actually delivers to the load. The efficiency simply tells you how much of the power that the stages take from the power supply is converted into a useful output signal. If the efficiency is 75% then 75% of the power input is converted to useful output and only 25% wasted. If an amplifier with 75% efficiency has a power input of 100 watts, the output will be 75 watts; the wasted power 25 watts. On the other hand, a 1000-watt amplifier with an efficiency of 30% would put out 300 watts of useful power, which is more than the preceding example, but in doing so would waste 700 watts.

Although the efficiency of the Doherty circuit is high, it has some important disadvantages. At high frequencies, the capacity in the phase-correcting circuit and the quarter-wave line is so small that even the stray capacity in the wiring and the tube capacities can affect the operation of the stage. Also, as the operating frequency increases, it becomes more and more difficult to maintain the proper phase relationships in the circuits.

Distortion will occur when a signal with a low modulation percentage is amplified by the Doherty system, because the peak tube then operates near cut-off where the characteristic of the tube is the most non-linear. Operating the carrier tube near saturation can also produce distortion. Other disadvantages of the Doherty circuit are that it presents a varying load to the preceding amplifier, and the circuit is very difficult to adjust. For these reasons, the Doherty amplifier is no longer being manufactured. However, you may find them still in use in some broadcast stations.

The class B linear circuits that we have discussed in this section are typical of those found in both low-power and high-power transmitters. The power output, of course, depends on the tube type, the component rating, and the operating voltages and currents used in the stage.

FEEDBACK SYSTEMS

You have already studied both regenerative and degenerative feedback. You will remember that when a signal is fed from the output of one stage back to the input of the stage, or to a preceding stage, we have feedback. If the polarity of the signal that is fed back is such that it aids the original signal, we have regenera-

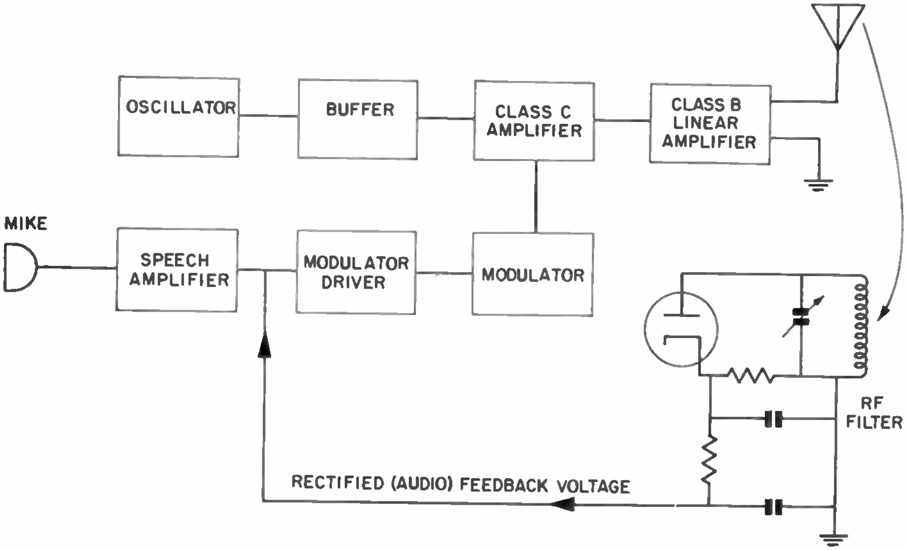


FIG. 13. Over-all rf to af feedback that reduces distortion, hum, and noise in the modulated class C and class B amplifier stages as well as in the audio-frequency amplifiers on the modulator.

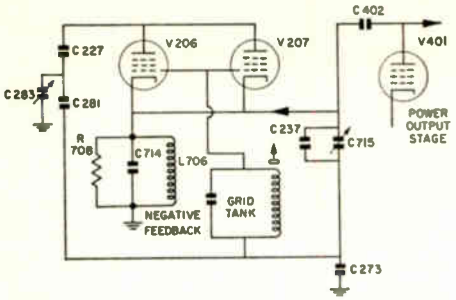


FIG. 14. The Collins rf feedback arrangement.

tive feedback, and if it opposes the original signal we have degenerative feedback, which we usually call inverse feedback. Regenerative feedback is used in oscillators. Inverse feedback is used to help reduce noise, hum, or distortion produced in amplifiers.

Inverse feedback systems are used in transmitters to reduce noise and distortion. A feedback system used in a transmitter is shown in Fig. 13. This feedback will reduce noise and distortion produced in the modulator driver, the modulator, the modulated class C stage and in the linear amplifier.

In this system there is a small resonant circuit that is tuned to the output frequency of the transmitter and loosely coupled to some portion of the output system such as the final tank circuit, or the transmission line, or picks up radiation directly from the antenna. It picks up the modulated signal, demodulates it, and filters out the rf. The demodulated signal, which is made up of the original audio signal plus any noise or distortion that has been added is then fed back to the speech amplifier or modulator of the audio system. It is reinserted 180° out of phase with the original signal.

In this system, noise or distortion originating in the modulator and its associated driver and amplifier stages, and distortion components contributed by the modulation process can be reduced to very low values.

Fig. 14 shows a system in which rf or carrier feedback is used. This is the Collins KWS-1 transmitter.

RF energy is fed back through capacitor C402 to the cathode circuit of the driver. Notice that the driver consists of two tubes, V206 and V207, connected in parallel. The feedback voltage developed between the cathodes of the driver and ground is 180° out-of-phase with the driver input signal. Hence, the feedback link includes the driver and the linear amplifier output stage. The feedback not only corrects distortion, but also improves the driver regulation, insuring a more linear operation.

The amount of feedback depends on the relative reactance of capacitors C402 and C714. Coil L706 is a radio frequency choke that provides a dc return for the cathodes. It is loaded by resistor R708 to prevent oscillation.

Outphasing Modulation System

A system of modulation in which linear amplifiers are not required has recently become more widely used. It is called the "outphasing" system or "phase-to-amplitude" modulation system.

As you have learned, in low-level modulation systems, the rf power amplifier stages must be operated linearly or the output will be distorted. However this is not the most efficient form of operation. In high-level modulation systems, the carrier is amplified before it is modulated, which eliminates the need for linear amplifiers, but much more audio power must be supplied to the class C stage to modulate it. Therefore, in low-level systems it costs more to amplify the carrier; in high-level systems it costs more to develop the high audio power required. The outphasing system combines some of the advantages of each. Let us see how.

BASIC SYSTEMS

Fig. 15A shows two ac generators connected in series across a load. If the two generators are exactly in phase, the two voltages they produce, E_1 and E_2, will add. For example, if each one is 10 volts, the total output will be 20 volts. This is shown by the vector diagram in Fig. 15B. The Greek letter phi (ϕ) is used to mean phase angle. Here it is shown as 0°.

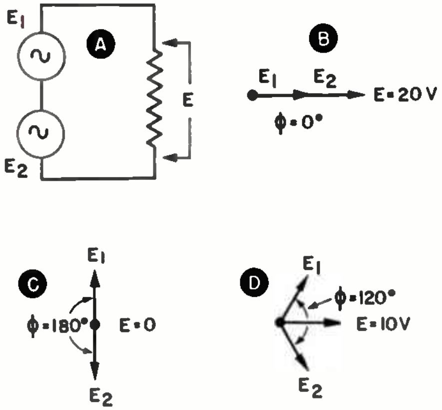


FIG. 15. Two generators connected in series across a load as in A, will produce varying voltages across the load, depending upon their phase relationship. B shows the output if they are in phase; C shows them 180° out of phase; and D shows them 120° out of phase.

If E_1 and E_2 are exactly opposite in phase, the voltages will cancel as shown in Fig. 15C. The phase angle is 180°, and the output voltage E is 0.

If the phase angle is anywhere between 0 and 180°, the output voltage will be somewhere between 0 and 20 volts. For example, if the phase angle is 120° as shown in Fig. 15D, the output voltage will be the vector sum of E_1 and E_2, or 10 volts. If the phase angle is varied, the output will also

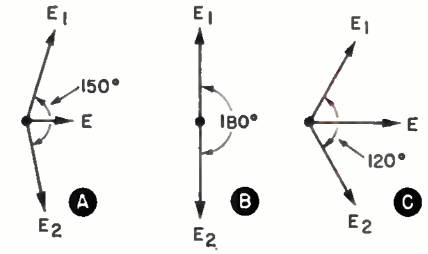


FIG. 16. Vector diagram showing how the combined output of two amplifiers depends upon the phase relationship between them.

vary in the same manner.

The generators in Fig. 15A can be replaced by vacuum tube amplifiers operating on the same frequency but out of phase by some value between 90° and 180°. If the amplifiers are then modulated with an audio signal that increases and decreases this phase difference between them in proportion to the amplitude of the audio signal, and if their outputs are then combined, the signal obtained across the output of the two amplifiers will be proportional to the modulating voltage. We will have 100% modulation if the modulating signal varies the phase of the carrier by the amount of the original phase shift away from 180°.

For example, if the amplifiers are operated with a phase difference of 150° without modulation (30° away from 180°), and 100% modulation is applied, the output will vary as shown in Fig. 16. The length of E indicates the amplitude of the output. When no modulation is applied, the carriers are 150° out of phase, and the output is equal to their vector sum, as shown in Fig. 16A.

On one half of the audio cycle, the phase difference will increase 30°, or up to 180°. The two carriers will cancel, and the output will be zero, as shown in Fig. 16B. On the other half of the audio cycle, the phase difference is decreased by 30°. This approximately doubles the output as shown in Fig. 16C.

Fig. 17 shows a block diagram of such a system. The output of an rf source is split between two amplifier branches. A phase shift of less than 180° is introduced into one branch so that the carrier will not be completely cancelled. The first tube in each string is a phase modulator. It is designed so that when an audio voltage is applied, the phase of its output will vary in step with the amplitude variations of the audio voltage. You will

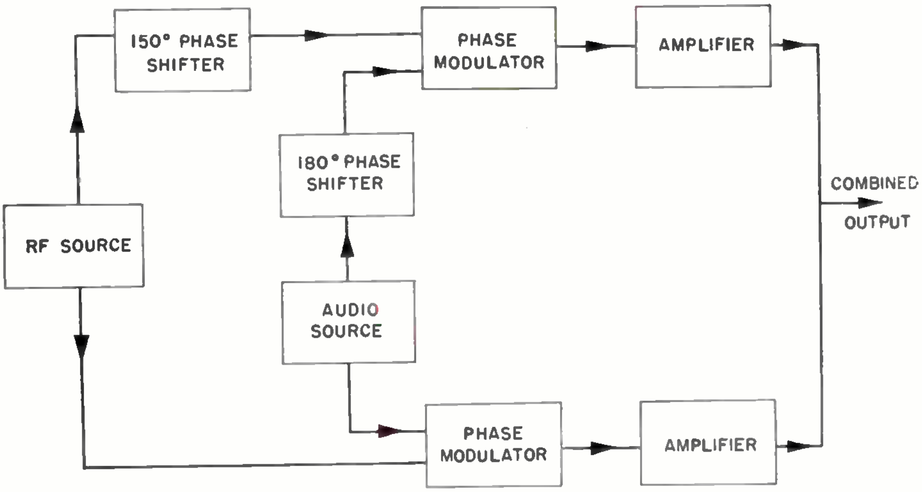


FIG. 17. Block diagram of basic outphasing modulation systems.

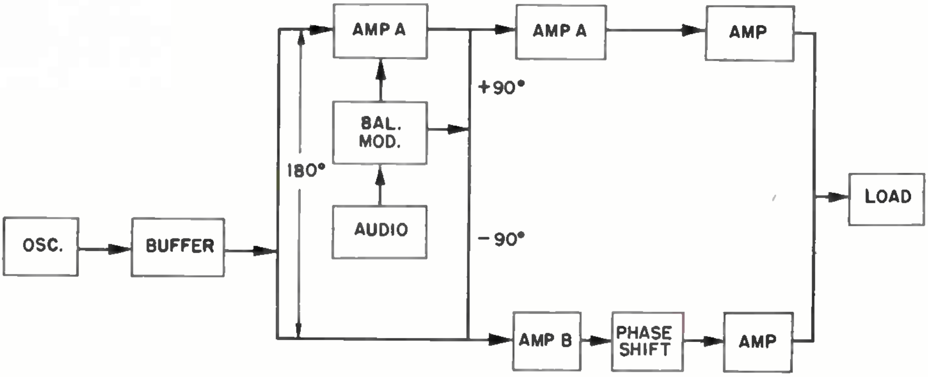


FIG. 18. Another basic outphasing modulation system.

learn how this is done in a later lesson on phase modulation. The audio voltages fed to the two phase modulators must be 180° out of phase with each other, or their effects would cancel.

The outputs of the two phase modulators are amplified, and the amplified outputs are combined.

The modulation envelope will not be distorted, regardless of whether the amplifiers are linear or not, because it is the phase not the amplitude of the signal that is varying in accordance with the audio, and the linearity of an amplifier does not affect the phase of the output.

Fig. 18 shows another arrangement for outphasing modulation. Here we have an rf source consisting of an oscillator and buffer stage. The output is fed to two amplifier strings, 180° out of phase. The audio signal is fed to a balanced modulator, which produces a double-sideband signal that is substantially free of carrier. The output of the modulator is divided between the two amplifier branches. One part is shifted +90° in phase and combined with the output of amplifier A, and the other part is shifted —90° in phase and combined with the output of amplifier B.

A small phase shift is introduced in the lower branch so that the carriers in the two branches will not cancel each other. After amplification, the two carriers are combined in the output. Since they are almost 180° out of phase with each other, the resultant carrier will be almost 90° out of phase with the carrier in each branch. Since the modulation sidebands were shifted 90° in phase at the output of the balanced modulator, they will be practically in phase in the output of the amplifier. Thus the original modulation appears in the

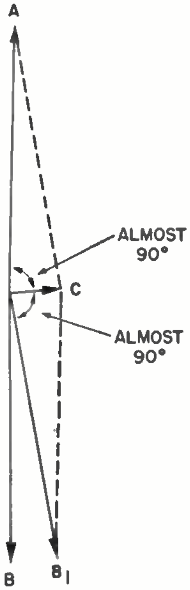
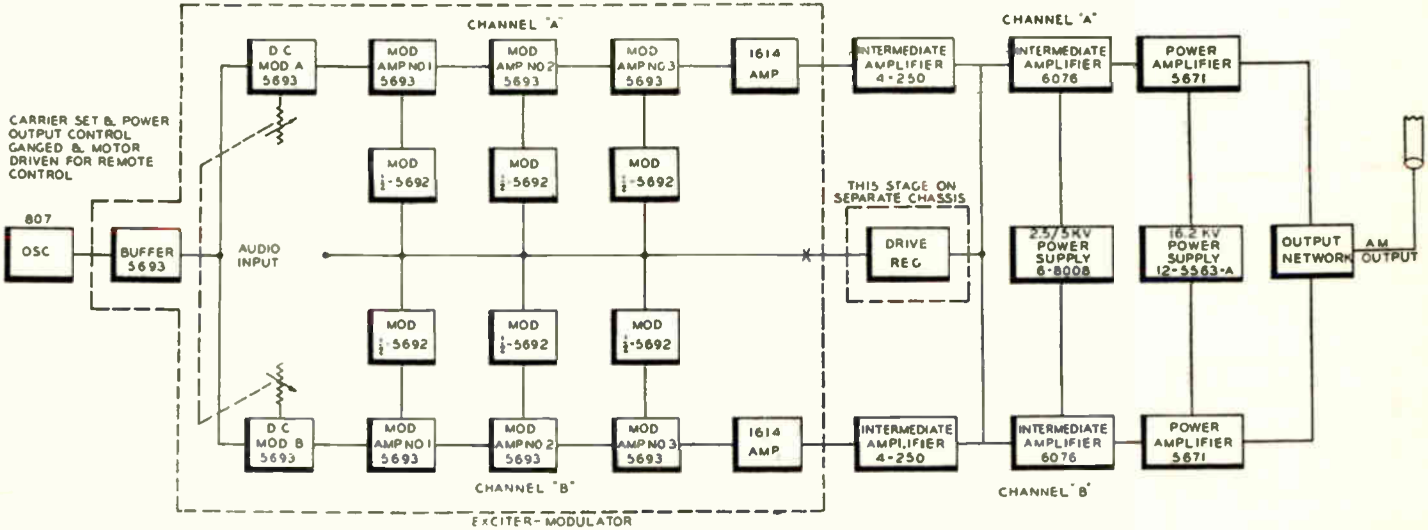
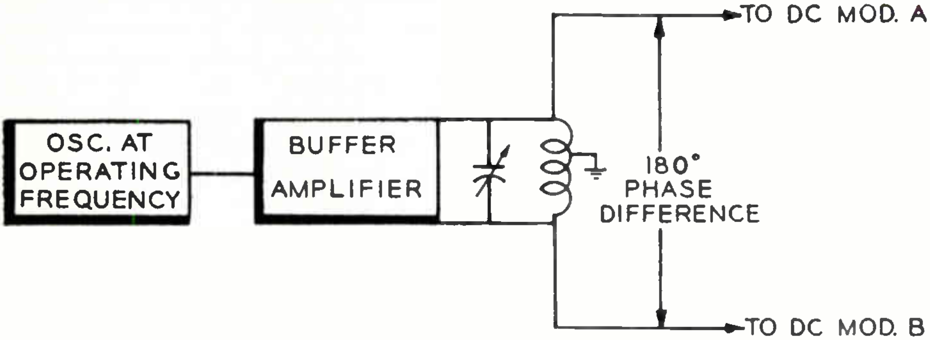


FIG. 19. Relationship of carriers in Fig. 18.



Courtesy RCA

FIG. 20. Block diagram of RCA Ampliphase transmitter.



Courtesy RCA

FIG. 21. Exciter-modulator circuit of Fig. 20.

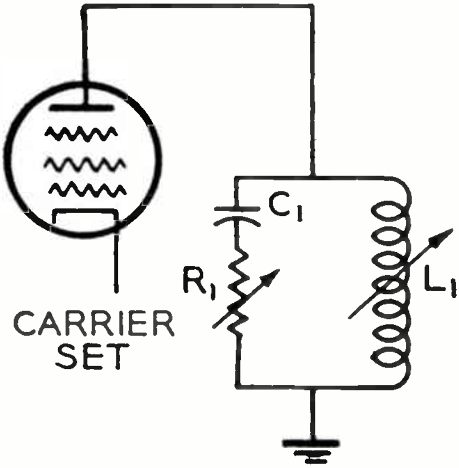
output. Fig. 19 shows the vector diagram for the carriers. A is the original carrier fed to amplifier A. B is the original carrier fed to amplifier B. B_1 is the carrier in the lower branch after being shifted slightly in phase. C is the resultant carrier in the output. As you can see, it is almost 90° different in phase from the carriers in the two amplifier branches.

THE RCA AMPLIPHASE TRANSMITTER

A modern commercial transmitter that uses this "phase-to-amplitude" system of modulation is the RCA 50-kw "Ampliphase" transmitter. A block diagram of this transmitter is shown in Fig. 20. Its operation is essentially similar to that of the circuits we have studied..

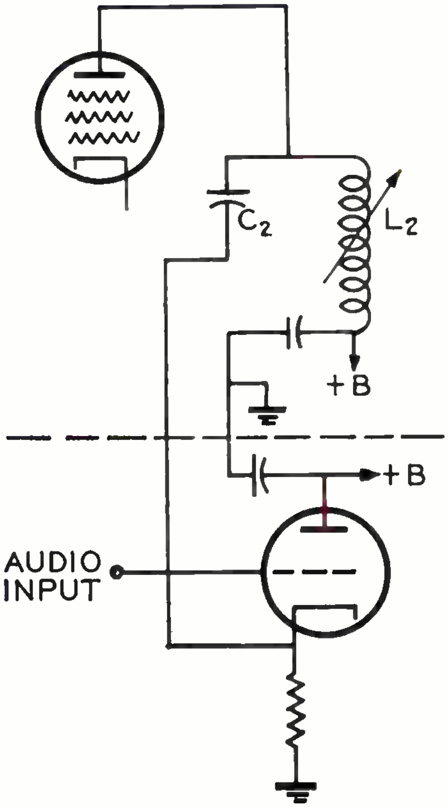
The output of a single crystal oscillator is fed to a buffer amplifier with a push-pull output tank, as shown in Fig. 21. Thus, the carrier wave is split between two rf amplifier channels, and the signal supplied to one chain is 180° out of phase with that supplied to the other. Since these two signals are 180° out of phase, no output would be obtained if they were impressed on a common load. However, if the phase difference is made less than 180°, some output will be obtained, the amount depending upon the phase angle.

So that the phase difference will be less than 180°, the first stage in each amplifier is an adjustable phase-shift amplifier. These are dc modulator A and dc modulator B in Fig. 20. A simplified diagram of the circuit is shown in Fig. 22. The values of L_1, C_1, and R_1 are chosen so that when R_1 is set to one end of its range, there will be a phase shift of +25°, and when it is set to the other end of its range, there will be a phase shift of −25°. Setting the phase-shift amplifier in one chain for a +22.5° phase shift, and the phase-shift amplifier in the other chain for a −22.5° phase



Courtesy RCA

FIG. 22. Simplified diagram of the adjustable phase shifter.



Courtesy RCA

FIG. 23. Simplified diagram of the modulated amplifier and modulator.

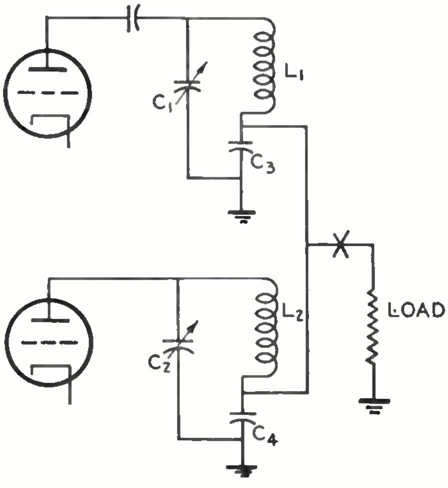
shift will give a total phase shift of 45°, and the two carriers will be 135° apart in phase instead of 180°.

The next three stages in each channel are called modulated amplifiers. They are quite similar to the adjustable phase-shift stages, except that instead of a variable resistor in the plate tank circuit there is a triode tube, as shown in Fig. 23. The triode tube acts as a variable resistance when an audio signal is applied to its grid. The audio signal applied to each modulator tube produces a phase-modulated signal in the tank circuit of its corresponding modulated amplifier.

Following the modulated amplifiers there is a conventional amplifier stage providing isolation and drive to the first intermediate power amplifiers. The signals are further amplified and then combined in the output to give an amplitude-modulated output. Fig. 24 shows a simplified diagram of the power amplifier output circuit.

The relationship between the carriers in the two channels is shown in vector form in Fig. 25. The two vectors A_1 and B_1 show the relationship of the carriers in the two branches without modulation. C_1 represents the output with no modulation. Vectors A and B show the carriers during the modulation troughs with 100% modulation, and A_2 and B_2 show the carriers on the peaks of 100% modulation. On the troughs the output is zero, and on the peaks, the output is doubled, as shown by C_2.

A very important consideration in designing transmitters is the amount of time a transmitter must be off the air if anything goes wrong. To minimize this time, the RCA Ampliphase transmitter is designed with two complete oscillators and two complete exciter-modulator sections. Either of these can be switched in with only a



Courtesy RCA

FIG. 24. Simplified diagram of the power amplifier output circuit.

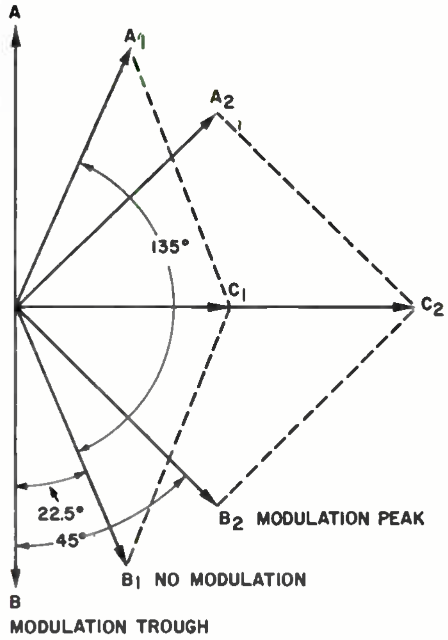


FIG. 25. Relationship of the carriers in the two amplifier channels of Fig. 20 for no modulation and 100% modulation.

momentary loss of carrier, and without cutting off the dc supply to the transmitter. Fig. 26 shows the switching arrangement.

Provision is also made for remote control of the transmitter. Because of the extra oscillator and exciter-modulator sections that can be switched in at a moment's notice, one of the big disadvantages of remote control operation is eliminated, that is, of having to lose time on the air while a maintenance man is sent to the transmitter.

Switching from local to remote control is accomplished with a single transfer switch. A safety feature is that this switch can be operated only at the transmitter. This eliminates the possibility that someone working on the equipment will be endangered by someone operating it from the remote point.

Meter readings for the total plate current, output plate voltage, driver plate voltage, carrier level, and both output cathode currents are repeated at the remote control point.

Broadly tuned band-pass coupling circuits are used to insure stability. A special transformer-type of neutralization circuit is used to make the final amplifiers completely broadband.

LOOKING AHEAD

Class B linear amplifiers are important because they are used in many AM radio broadcast stations. They are used because it is more economical to modulate a low-power class C stage and then amplify the modulated signal than it is to modulate a high power class C stage.

Remember that class B linear amplifiers are operated at extended cutoff bias. If the amplifier is properly adjusted, the plate current will not change when the amplifier is modulated. If there is a meter in the transmission connecting the transmitter to the antenna, the current reading on this meter should increase 22.5% with 100% modulation.

Distortion will be produced in a linear amplifier that is overdriven because the plate current is not able to follow the grid voltage variation if the tube is driven beyond saturation. Distortion may also be due to improper bias on the linear amplifier, or poor driver regulation.

Most linear amplifiers that you en-

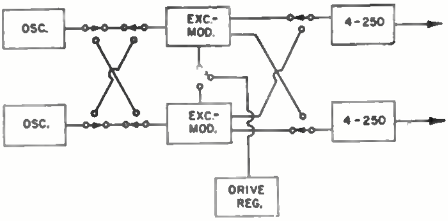


FIG. 26. Arrangement for switching in extra oscillator or exciter-modulator in Fig. 20.

counter in AM broadcast work will be class B amplifiers. However, class AB linear amplifiers are also used, particularly in single sideband applications. You will study these amplifiers later, and also class B amplifiers for TV. When you study these amplifiers, you will find that the plate current of these linear amplifiers does not remain constant when they are modulated.

One method of getting around the necessity of using linear amplifiers is to use a combination of phase and amplitude modulation, as in the Ampliphase system. You will learn more about phase modulation in a later lesson.

Lesson Questions

Be sure to number your Answer Sheet 21CC.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of lessons before new ones can reach you.

1. Why can't class C amplifiers be used to increase the power of the modulated signal from an AM transmitter?

2. What TWO operating adjustments on a properly tuned linear stage have most effect on the linearity?

3. What makes it possible to use a single tube in a class B rf linear amplifier, when two tubes in push-pull are needed in a class B audio amplifier?

4. How does the plate current meter reading in a class B linear amplifier in an AM broadcast station react when modulation is applied?

5. In which of the following operating conditions is less power dissipated in the class B linear tube: (a) *with modulation* (b) *without modulation?*

6. If the final class B linear amplifier stage in a transmitter has an output of 50 kw and an efficiency of 40%, how much power must be dissipated by the tubes?

7. List three causes of positive carrier shift in a linear amplifier stage.

8. Why are the grid and plate voltages in a linear amplifier set to one-half their normal values during adjustment?

9. What is the output voltage when two generators generating equal voltages 180° out of phase are connected in series?

10. When the output of an Ampliphase system is at its maximum, will the phase difference between the two amplifier signals be (a) *maximum* or (b) *minimum?*

THOROUGHNESS

Whatever you do, do well if you would stay on the straight road to success. The habits of carelessness and slipshod work are all too easy to acquire; beware of them as you would the plague. Men who are thorough in their work cannot remain undiscovered for long, because the demand for such men is greater than the supply.

Thoroughness is just as important in study as it is in work; what you get out of a lesson depends upon how completely you master the material presented in it. Some books, as fiction, are read hurriedly and only once, then cast away; the enduring works of literature are carefully read and reread many times but always essentially for the pleasure they give; textbooks, however, must be read quickly to get the basic ideas, then carefully many times until every important principle has been mastered.

Thoroughness in study habits leads to thoroughness in work habits, and eventually to a thorough success.

J. M. Smith


nri

RADIO • TELEVISION COMMUNICATIONS

CURRENT, VOLTAGE AND RESISTANCE MEASUREMENTS

22CC

NATIONAL RADIO INSTITUTE • WASHINGTON, D. C.

CURRENT, VOLTAGE, AND RESISTANCE MEASUREMENTS

22CC

STUDY SCHEDULE NO. 22

☐ 1. **Introduction** ....**Pages 1-3**

Here you get a general idea of how meters are used, meter accuracy, and why meters are shielded.

☐ 2. **Basic Meter Movements** ....**Pages 3-8**

You study the three basic types of meter, the d'Arsonval, the moving vane, and the dynamometer.

☐ 3. **DC Measurements** ....**Pages 8-18**

First we take up direct current measurements then dc voltage measurements.

☐ 4. **AC Measurements** ....**Pages 19-25**

We take up alternating current measurements then ac voltage measurements.

☐ 5. **Resistance Measurements** ....**Pages 25-32**

We discuss series and shunt ohmmeters, meggers, and multimeters.

☐ 6. **Power Measurements** ....**Pages 32-36**

Here you learn how dc power, 60-cycle power, and af and rf power are measured.

☐ 7. **Answer Lesson Questions.**

☐ 8. **Start Studying the Next Lesson.**

MP2M469 **1969 EDITION** Printed in U.S.A.

CURRENT, VOLTAGE, & RESISTANCE MEASUREMENTS

METERS play an important part in all phases of electronics. They are used to find out what is going on in an electronic circuit, for making operating adjustments, in checking performance, and in troubleshooting. In communications work you will deal with meters that are wired right into transmitter circuits to indicate operating conditions, and also with portable test instruments. Sometimes, you may want only a general indication of current, voltage, or resistance; sometimes you may have to take very accurate measurements, but whether the measurement is general or very exact, its usefulness depends on how well you understand your instrument. If you misuse a meter, you will get inaccurate readings, and may damage the meter.

In this lesson, we will discuss meters used to measure current, voltage, resistance, and power. You will learn that the same types of meter are used in all measuring circuits. It is the arrangement of the meter circuit and the way in which the meter is connected that determines the type of measurement that will be made.

We will discuss only meters that do not use vacuum tubes as part of their circuits here. In a later lesson we will take up vacuum-tube voltmeters and other instruments using vacuum tubes.

Most meters used in electronics rely on the principles of electromagnetism. That is, when current flows through a coil of wire, a magnetic field is produced around the coil that is proportional to the amount of current flowing. This principle is used in the three most common types of meters: the d'Arsonval, the magnetic vane, and the dynamometer. We will discuss these three types. No matter which type it is, the moving element is made as light as possible. Because the moving element is light it will move quickly and have a tendency to oscillate somewhat back and forth through the correct reading. There must be some means of bringing the pointer to rest quickly without oscillation after the meter has been energized, and to keep it from swinging back and forth after it is brought back to zero. This is called "damping." It can be accomplished either electrically or mechanically. You will see examples of both systems.

ACCURACY

Although it is possible to make highly accurate meters (within one-quarter of 1% or better) by hand-calibrating them with a standard meter, they are large and very expensive. For general communications work, meters having an accuracy of 2% are satisfactory. These meters are mass-produced, with printed scales, and are adjusted internally at the time they are manufactured to the required accuracy.

The accuracy of a meter movement is generally expressed as a percentage of the full-scale reading. For example, if a meter with 50 scale divisions has 2% accuracy, it is accurate within one scale division at the *full-scale* reading. This does not indicate the per cent of accuracy on the rest of the scale, because it may be off as much as one scale division at any other part of the scale also. For example, when the meter pointer is at the tenth division (1/5 of full scale), the reading may still be in error by one division; this would be an error of 10%. Most instruments used in communications work have a 2% accuracy at full scale, but not as much error as 10% at the low end of the scale.

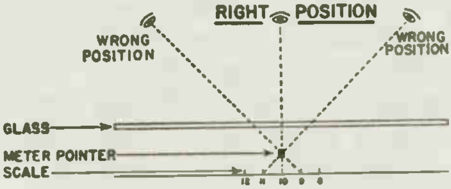
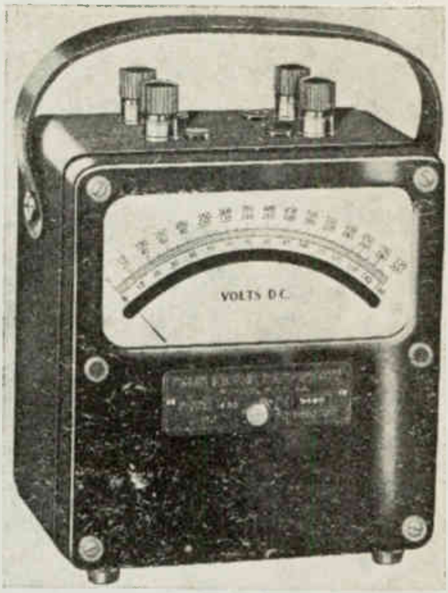


FIG. 1. When reading a meter, always look at it directly to get an accurate reading.



Courtesy Weston Electrical Instrument Co.

FIG. 2. A portable dc voltmeter. The dark arc below the scale is a mirror to make it easier to read the meter accurately.

Reading the Meter. In order to get an accurate reading from a meter, you must look at it squarely, not from an angle, because in order to swing freely, the pointer must be a little bit above the scale. As shown in Fig. 1, if you look directly down on the meter you will get one reading, for example, 10. However, if you look at it from one side, you might think the reading was 9, and from the other, you might think the reading was 11.

To help avoid this, many meters have a mirror under the pointer. The dark area under the scale in the meter shown in Fig. 2 is such a mirror. When you read the meter, you move your eye until the reflected image of the pointer disappears, and you know you are looking directly at it.

Shielding. It is sometimes desirable to shield the meter elements, because external magnetic fields produced by nearby current-carrying conductors or by the earth itself can react with them and affect the readings. There is no known insulator for magnetic lines of force, so the undesirable stray fields must be bypassed around the meter elements by a shield made of iron, which is a good conductor of magnetic lines of force. Such an arrangement is shown in Fig. 3.

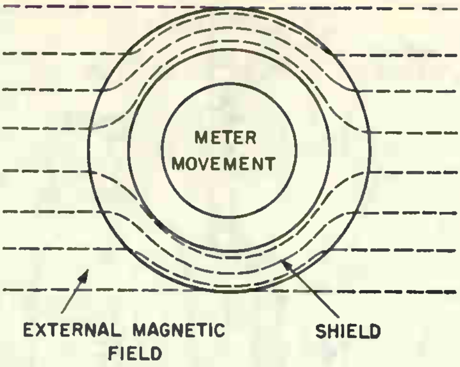


FIG. 3. A meter can be shielded from an external magnetic field by encasing it in iron, which bypasses the field around the meter movement.

Now, let's take a look at the basic types of meters, and then see how they are used to measure current, voltage, resistance, and power.

Basic Meter Movements

The three types of meters we will discuss in this section are the d'Arsonval, the magnetic vane, and the dynamometer. All three types can be used for both ac and dc measurements; however, the d'Arsonval is by far the most common for dc. When the d'Arsonval is used to measure ac, it must be used with a rectifier to change the ac to dc. Since the d'Arsonval is the most common type, let's discuss it first.

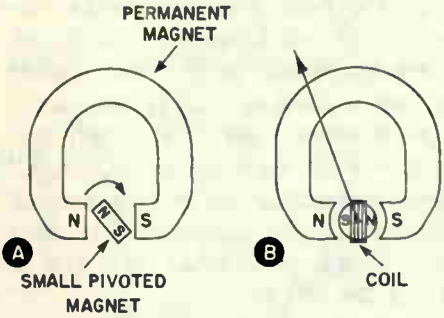


FIG. 4. A small pivoted magnet placed between the poles of a large magnet as at A, will rotate until the unlike poles are opposite each other. A pivoted coil through which current is passed will act in the same way, as shown at B.

THE D'ARSONVAL METER

In an earlier lesson, we had a quick look at the d'Arsonval meter. Let's review its action now. As you will remember, it works on the principle that like magnetic poles repel each other and unlike magnetic poles attract. If a small pivoted magnet is placed between the poles of a permanent magnet, as shown in Fig. 4A, it will move in the direction of the curved arrow.

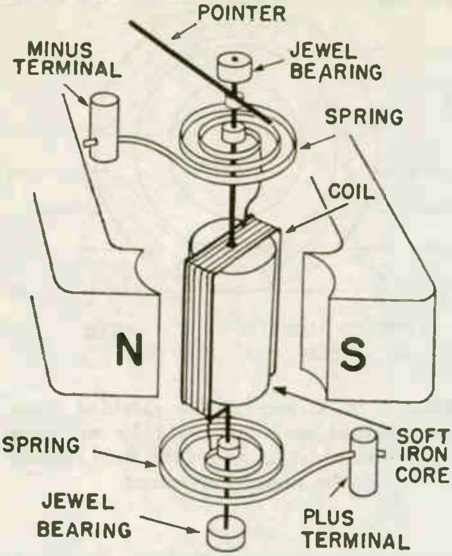


FIG. 5. How a d'Arsonval type of meter is made.

Now, suppose instead of the small magnet we put a coil between the poles of the larger magnet. As you know, when current flows through a coil it becomes magnetized. Therefore, if we send current through this coil, it will act just like the small permanent magnet in Fig. 4A. This is the way the d'Arsonval meter is made, as shown in Fig. 4B. The coil is wound on a soft iron core, and placed on a pivot, and a pointer is attached to the coil. When no current is applied, the coil and the pointer are in the position shown. When current is applied to the coil, it becomes magnetized and starts to rotate, moving the pointer.

The coil would continue to rotate until its south pole was opposite the north pole of the permanent magnet, except for the fact that springs are attached to the ends of the coil, as shown in Fig. 5, which oppose the coil movement. Therefore, the coil turns only to the point where the magnetic force caused by the current is exactly equal to the retarding force of the springs, and remains there as long as the current causing the magnetic force is applied. When current stops, the magnetic field of the coil disappears, and the springs move the coil back to its original position.

Since the magnetic force causing rotation of the coil is proportional to the amount of current flowing through the coil, one particular value of current will make the coil rotate to one particular place. A greater current will rotate the coil further, and a smaller one will rotate it less. A scale that is marked to show the amount of current that will cause any particular amount of movement is placed under the pointer.

The permanent magnet is made from a special steel or metal alloy, chosen for strong magnetic qualities and long magnetic life. The stronger the field of the permanent magnet, the more the coil will rotate for a particular current; in other words, the more sensitive the meter will be. The magnet is especially treated and aged until the field strength remains constant. The pole pieces are of soft iron, carefully shaped to give the desired magnetic distribution. If the meter scale is to be linear (that is, adjusted so that equal increases in current will produce equal increases in meter coil movement), the magnetic field must be uniform throughout the gap in which the coil turns.

So that it will turn easily, the coil is wound on a very light-weight metal form, and the coil and the form are suspended between almost frictionless pivots with jewel bearings. The number of turns used in the coil depends on the range and sensitivity desired for the meter.

The coil starts to rotate from the same position each time. When the coil rotates, one spring is wound while the other is unwound. The springs thus oppose the coil movement in either direction away from the starting position.

Naturally, these springs will not always remain perfectly balanced. Most meters have a zero adjustment to compensate for this. It is a small screw that usually protrudes through the case of the meter just above or below the meter coil. Turning this screw moves the upper spring enough to balance the springs and bring the meter pointer back to the zero position.

The springs are also used to make electrical connections to the coil. Of course, this means that they must be insulated from each other and from the meter frame.

Damping. In the d'Arsonval meter, the damping is done electrically by winding the coil on an aluminum frame. As the coil responds to the flow of current and starts to rotate, a voltage is induced in the aluminum frame as it cuts the lines of force of the permanent magnet. The induced voltage causes a current to flow in the frame, which in turn produces a magnetic field opposite to that of the permanent magnet. The opposing field produces a braking action which brings the pointer quickly to rest. When the coil comes to rest, no voltage is induced in the frame. Therefore, there is no field produced by the frame to interfere with the fields of the coil and of the permanent magnet. The same action takes place when the meter is de-energized and the pointer is returned to zero.

Another common method of creating damping is to place a resistor between the meter terminals. In this system, there is a voltage induced in the coil as it moves through the fixed field, which causes a current flow through the resistor and coil that sets up an opposing field similar to that produced by the current induced in the coil form. In both cases, damping action ceases as soon as the coil stops moving. The resistor value that will permit the most rapid coil movement without noticeable waving and still give full-scale meter reading is called the critical damping value. This value varies widely. Some meters require 10,000 ohms, others 100 ohms. Too small a resistor causes over-damping and a slow movement, whereas too large a resistor does not damp enough.

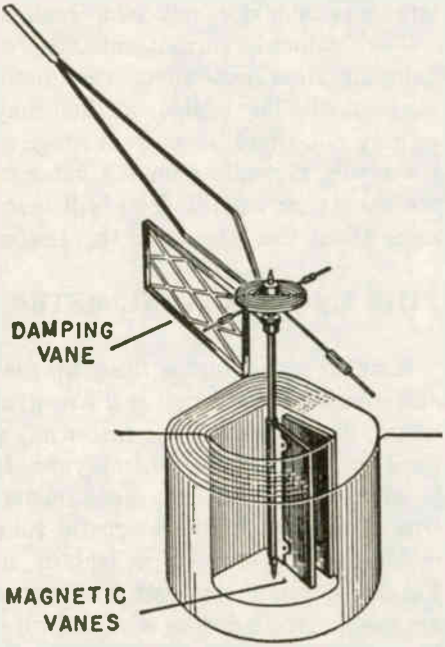
The induced current method of damping does not affect the meter range at all. The resistor method may or may not affect the current range of the meter, depending on the value of the resistance needed. You will learn more about this later on in this lesson.

THE MAGNETIC-VANE METER

Instead of having a fixed magnet and a moving coil like the d'Arsonval meter, the magnetic-vane meter has a fixed coil and a movable iron vane. It is often called an iron-vane meter. One of the best of the magnetic-vane meters is the book-type, shown in Fig. 6. In this meter, two iron vanes are used, surrounded by a coil of wire. When current flows through the coil, the vanes will be similarly magnetized so they will repel each other. It makes no difference whether the energizing current is dc or ac, the vanes will still repel each other. One vane is fixed, and the other is pivoted and attached to a pointer. The movement produced is shown on a scale under the pointer. Hair springs are used to control the motion and return the pointer to zero when no current is being applied to the coil.

The moving vane meter is not as widely used as the d'Arsonval meter for a number of reasons. The meter cannot be made as sensitive as the d'Arsonval meter and therefore cannot be used to measure very weak currents. Also the scale is not linear; the lower quarter of the scale is usually quite compressed.

Furthermore, when used on dc, the polarity of the current through the coil may have some effect on the reading, so it is best to take a reading, reverse the polarity, then take another reading, and average the two.



Courtesy Weston Electrical Instrument Co.

FIG. 6. A magnetic vane meter.

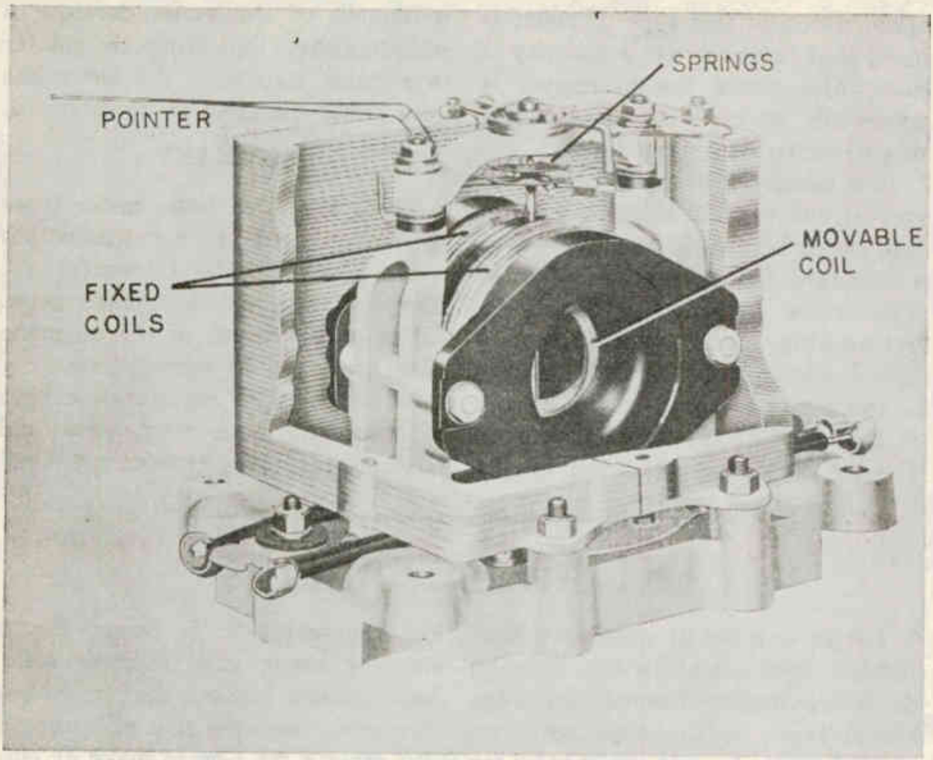
In addition, the meter cannot be used on high ac frequencies because of losses in the vanes. Both eddy current and hysteresis losses become appreciable as the frequency increases. In fact, these meters are usually calibrated for use at some specific frequency and if measurements are taken at another frequency, the percentage of accuracy of the measurements will be somewhat less than the rated accuracy of the meter.

Damping. A mechanical method of damping is used in this meter. The aluminum vane shown directly under the pointer is used to slow down the movement of the pointer. This vane fits quite snugly into the space inside of the coil. Both ends of the opening are closed, so the vane, in moving through the air in the enclosed space, is held back by the air pressure developed. This effectively damps any tendency of the vane and pointer to oscillate.

Several other types of magnetic vane movements have been developed, but the book type is the most sensitive and the most accurate. All have similar characteristics that restrict their use to dc and low-frequency ac measurements.

THE DYNAMOMETER

The dynamometer, or electrodynamometer as it is sometimes called, operates because of the reaction between the magnetic fields of a fixed coil and a movable coil when the same current flows through both of them.



Courtesy Weston Electrical Instrument Co.

FIG. 7. A dynamometer.

Actually, there are generally two fixed coils and one movable coil. Fig. 7 shows this type of meter.

The fixed and movable coils are in series, so the same current flows through them. When no current is flowing, the axis of the movable coil is at right angles to the axis of the fixed coils. This position is maintained by control springs.

When current flows through the coils, it sets up magnetic fields around them. Because of the physical position of the coils, the magnetic field of the movable coil is at right angles to the magnetic field of the stationary coils. As you know, like magnetic poles repel and unlike magnetic poles attract each other, so the two fields try to align themselves. This causes a turning force, or torque, which carries the pointer clockwise across the scale until the restraint of the springs equalizes the torque. The pointer then comes to rest. The deflection of the pointer is proportional to the square of the current. Therefore, the scale used with the dynamometer has nonlinear scale divisions.

It doesn't make any difference whether the current applied is ac or dc, because if it is ac it will change direction in the movable coil and the stationary coils at the same instant so that the two magnetic fields will still oppose each other.

Since there is no iron core to produce an economical flux, the power consumption of this type of meter is high; that is, the power sensitivity is poor. Also, since the movement is necessarily heavy, it is a slow-acting meter compared to other types.

It is usually calibrated with direct current and is often called a transfer instrument because it can be used as a standard for calibrating other ac instruments.

Damping. A mechanical method of damping is used in Fig. 7. It consists of two vanes attached to the bottom of the shaft of the moving element. The air turbulence produced by the movement of the vanes develops a retarding effect that brings the pointer to a quick stop after the meter has been either energized or de-energized.

SUMMARY

There are three basic meter types commonly used in communications work. These are the d'Arsonval, the magnetic vane, and the dynamometer. All operate because of the magnetic effect produced by current flow.

All three types require some kind of damping. Both mechanical and electrical damping systems are used

DC Measurements

The three types of meters we have just discussed can all be used to make dc measurements. However, the d'Arsonval meter is the most sensitive, and is itself a dc meter, so it is by far the most widely used for dc measurements. In fact, in communications work, you will probably use only d'Arsonval meters in making dc measurements.

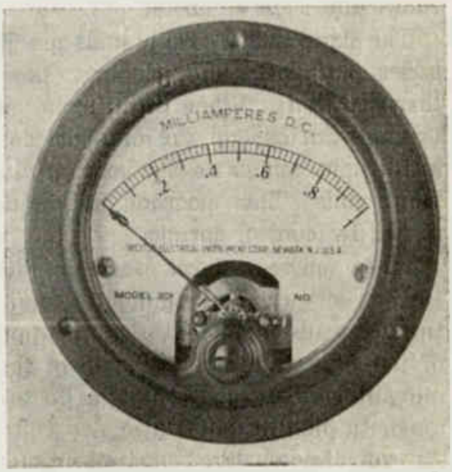
Practically all dc ammeters and voltmeters using d'Arsonval movements have linear scales. That is, the spacing between scale divisions is exactly the same over the whole scale. Let's see why.

The air gap in which the moving coil rotates is designed to give a uniform magnetic field in all of the space through which the coil moves. The torque or turning force exerted by the coil against the springs will be directly proportional to the current flowing through the coil. Since the springs allow the coil to turn by an amount proportional to the current, and the scale will be linear. Fig. 8 shows a meter with a linear scale. Each division between the longer lines represents one-tenth of a milliampere.

Now let's see how to make dc current measurements.

MEASURING DIRECT CURRENT

Current meters measure the flow of



Courtesy Weston Electrical Instrument Co.

FIG. 8. A milliammeter with a 1-milliampere linear scale.

electricity in a circuit. To make the measurement, the meter must be connected in series with the source and the load as shown in Fig. 9. Current meters that are used as operating indicators are wired into the circuit permanently. When a current meter is used as a temporary test instrument, the circuit must be broken so that the meter can be connected in series with the load.

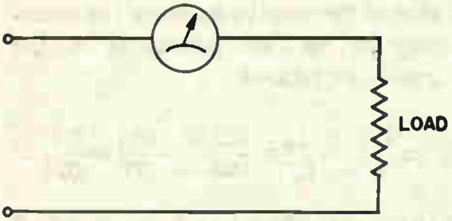


FIG. 9. A current meter is connected in series with the source and load as shown here.

When making temporary measurements, you must be sure to use a meter with a high enough range. If you are in doubt, use a very high range, and switch to a meter with a lower range if you find that the current is low enough to permit you to do so.

The amount of current flowing in transmitter and receiver circuits varies considerably, from a few milliamperes in some low-level stages to several hundred amperes in the filament circuits of the final amplifier in a high-power transmitter.

Meters are made in a wide variety of full-scale ranges, but it would not be practical to keep on hand meters for every conceivable range. However, it is possible to extend the range of a milliammeter to measure higher currents. Let's see how this is done.

EXTENDING METER RANGES

When currents up to 5 milliamperes are to be measured, usually a meter having a basic range that covers the range to be measured is used. For example, if the currents to be measured are under 1 ma, a 1-ma meter is used. If currents up to 3 ma are to be measured, a 3-ma meter is used. When currents over 5 ma are to be measured, resistors called "current shunts" are connected in parallel with the meter movement to extend the range.

Suppose we have a 1-milliampere meter and want to measure currents up to 10 milliamperes. We can do so by putting a resistor across the meter terminals. We choose the value of the resistor so that nine-tenths of the current (9 milliamperes) coming into the resistor-meter combination will flow through the resistor and one-tenth (one milliampere) through the meter. In other words, we use the resistor to bypass nine-tenths of the current. Fig. 10 shows how this is done. Since nine-tenths of the total current flows through the shunt, the shunt must have a resistance that is only one-ninth of the resistance of the meter.

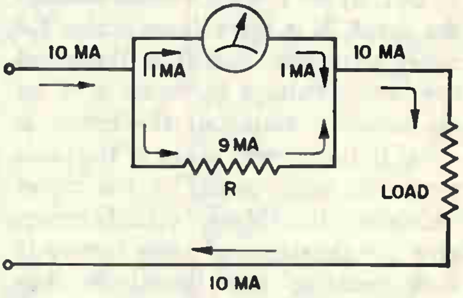


FIG. 10. How a shunt is used to increase the range of a milliammeter.

Since the meter is a 1-milliampere

meter, the scale will be calibrated like the meter scale shown in Fig. 8. However, by connecting the shunt across it we have converted the meter into a 10-milliampere meter. Therefore, to determine the current flowing in the circuit you must multiply the meter reading by 10. Thus a reading of .6 milliampere on the meter indicates a current of 6 milliamperes in the circuit.

Since the current bypass resistor R makes a parallel path around the meter, it is called a shunt. The ohmic value of R is calculated so that it will pass a current that is the difference between the total current being measured and the amount of current the meter needs for full-scale deflection.

It's easy to find the shunt resistance to change the current that can be measured by a meter. For example, if we have a 1-milliampere meter, and we want to measure currents up to 25 milliamperes, we must use a shunt that will pass 24 milliamperes. To find its value, we use Ohm's Law, $R = E/I$, where I is the current through the shunt, E is the voltage across the meter terminals, and R is the shunt resistance. Voltage E, which is called the millivolt rating of the meter, is equal to the current range of the basic meter, I_m, multiplied by the meter resistance R_m. Meter manufacturers give the resistance of their meters in their catalogs and sometimes they also mark it on the back of the meter. In a few cases they also give the millivolt rating of the meter. Current I through the shunt equals the total current, I_t, minus the basic meter current, I_m. Therefore, by substituting $R_m \times I_m$ for E, and $I_t - I_m$ for I, our Ohm's Law equation can be written:

$$R = \frac{R_m \times I_m}{I_t - I_m}$$

If we figure all the current values in the same unit (amperes, milliamperes, or microamperes), the answer will come out in ohms.

Now, suppose the resistance of our 1-ma meter is 100 ohms; to find the value of the shunt necessary for measuring 25 ma, we substitute in the formula as follows:

$$R = \frac{R_m \times I_m}{I_t - I_m} = \frac{100 \times .001}{.025 - .001} = \frac{0.1}{.024} =$$

4.166 ohms, which can be rounded off to 4.2 ohms with an error of less than 1%.

We could also have calculated the resistance from the fact that the shunt must pass 24 times as much current as the meter, and therefore must have a resistance that is 1/24 of the resistance of the meter. Therefore:

$$R = \frac{100}{24} = 4.166 \text{ ohms.}$$

To find the actual total current flowing, multiply the reading on the shunted meter by the ratio of the current range of the meter with shunt to the current range without shunt. In our example, a one-milliampere meter was made into a 25-milliampere meter so this ratio is 25/1. The meter readings must be multiplied by 25 to find the actual current flow. It is important to remember at this time that the meter itself is not passing 25 milliamperes; only 1 milliampere goes through the meter and 24 milliamperes go through the shunt.

You will remember that when we

spoke about damping we said that d'Arsonval meters are sometimes damped by connecting a resistance across the meter terminals. Also we mentioned that too low a resistance would result in over-damping, which causes the meter pointer to move very slowly. When we connect a shunt across the meter terminals we connect it in parallel with the damping resistor. Since the shunt resistance is usually less than the critical damping value of the meter we end up with an over-damped meter. This situation can be corrected to some extent by connecting a small resistance in series with the meter movement.

Let's consider the example we already have discussed where we converted a 1-milliampere meter with a resistance of 100 ohms to a 25-milliampere meter. We did this by connecting a 4.166-ohm shunt across the meter terminals. This shunt becomes the damping resistor. If the value of damping resistor required for critical damping is several hundred ohms, you can see the meter will be very badly over-damped.

Suppose we connect a 20-ohm resistor in series with the meter lead. Now the total resistance of the meter is 120 ohms. To shunt this combination so the meter will read full scale in a circuit when the current flow is 25 milliamperes, we need a shunt that has a resistance 1/24 of 120 ohms.

$$R = \frac{120}{24} = 5 \text{ ohms.}$$

Now with a five-ohm shunt connected across the meter and the 20-ohm resistor we added, the meter range will be 25 milliamperes as before. However, now the damping resistor is made up of the 20-ohm resistance we connected in series with the meter, plus the 5-ohm shunt. Thus, the total damping resistance is 25 ohms, which is over five times the value it was with the 4.166-ohm shunt. The meter will still be over-damped, but not nearly as much as before.

We mentioned before that meters designed to measure currents above 5 milliamperes are usually 5-milliampere meters with a shunt. Thus, a meter with a scale from 0-100 milliamperes consists of a 5-milliampere meter as the basic meter movement, with a shunt built inside the meter case. When the meter indicates a current of 100 milliamperes, 5 milliamperes will be flowing through the meter and 95 through the shunt. Similarly in the case of a 5-ampere meter, 5 milliamperes will flow through the meter and 4.995 amperes through the shunt.

You might wonder why meters are made this way. There are two reasons, it is more practical to build one basic meter movement and extend its range by shunts than to build a large number of basic meter movements. Another reason is that if high currents were used in the basic meter, the springs which conduct the current to the coil would be quite bulky. Also we would have to use a rather large wire size to wind the coil. This would make the moving coil assembly bulky and insensitive.

In small panel instruments having a range of about 20 amperes or less, the shunt is contained within the instrument. In portable instruments of high accuracy and in panel instruments having a rating of over 20 amperes, an external shunt is generally used with the meter.

Most meters designed for use with external shunts have a sensitivity of 50 millivolts. You will remember that we said the meter sensitivity in volts is equal to $I_m \times R_m$, where I_m is the full-scale meter current and R_m is the meter resistance. Thus, the meter sensitivity simply tells us the voltage across the meter terminals at full-scale deflection. If we have a number of meters that are all 5-milliampere meters and all have a 50-millivolt sensitivity, they must all have the same internal resistance. Thus, a shunt designed to work with one of these meters could be used with any of them. You will find shunts made for use with meters of this type. They are usually labeled 50 millivolts and are also labeled with the current range to which they extend the meter. For example, a shunt marked 50 millivolts-20 amps, is designed for use with any 5-milliampere meters that have a sensitivity of 50 millivolts. When it is connected across the meter terminals, the meter range will be extended to 20 amperes.

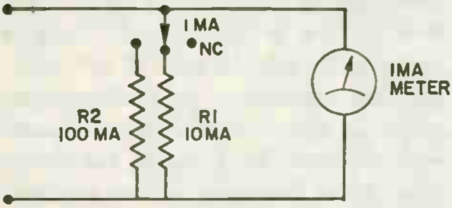


FIG. 11. A multi-range switch for connecting shunt resistances across a meter.

Many meters have several ranges, each with a separate shunt resistance. The shunts are connected into the circuit by means of a multi-range switch, as shown in Fig. 11.

Ring Shunts. Another arrangement of shunt resistors, called the "ring shunt" is shown in Fig. 12A. In this circuit, we have a meter with a 40-ohm, 5-milliampere movement, and a ring shunt arranged to extend the scale to 25 ma, 50 ma, and 250 ma.

The range switch is shown in the position for the 25-ma range. To find what the total resistance would be, we use our formula:

$$R = \frac{R_m \times I_m}{I_t - I_m}$$

The meter resistance is 40 ohms, the meter current is 5 ma (.005 ampere), and the total current is 25 ma (.025

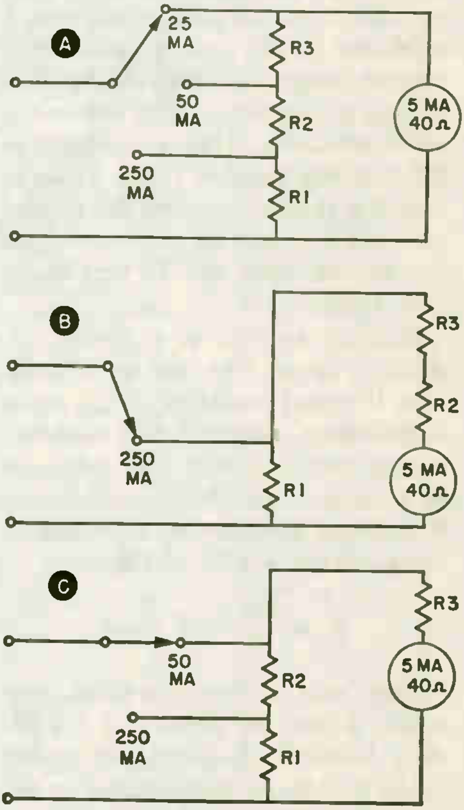


FIG. 12. How a ring shunt works.

ampere), so we have:

$$R = \frac{R_m \times I_m}{I_t - I_m} =$$

$$\frac{40 \times .005}{.025 - .005} = \frac{.2}{.02} = 10 \text{ ohms.}$$

We could also have determined the value of R using all currents in milliamperes. Thus it would work out:

$$R = \frac{40 \times 5}{25 - 5} = \frac{200}{20} = 10 \text{ ohms.}$$

Now we know that the total resistance of R1 + R2 + R3 is 10 ohms and the meter resistance is 40 ohms, so the total resistance in the circuit is 50 ohms, and we want to find the values of the individual resistances. Let's find the value of R1, first.

With the switch in the 250-ma position, the circuit could be redrawn as shown in Fig. 12B. Now the resistance of the meter is equal to 40 ohms *plus* the resistance of R2 and R3, or in other words, it is equal to 50 ohms *minus* the resistance of R1. The shunt is resistance R1 and its value can be calculated using the same formula as before. Now for R_m we substitute (50 — R1) which is equal to the total resistance in the meter circuit, 40 + R2 + R3. I_m, the current through the meter, is 5 milliamperes (.005 amps) as before, and I_t is 250 milliamperes (.250 amps). So in our formula, we have:

$$R1 = \frac{(50 - R1) \times .005}{.250 - .005} =$$

$$\frac{.25 - .005R1}{.245}$$

$$.245R1 = .25 - .005R1$$

$$.25R1 = .25$$

$$R1 = 1 \text{ ohm.}$$

The circuit with the switch in the 50-ma position can be redrawn as shown in Fig. 12C. Now the meter resistance R_m is equal to 40 ohms plus R3, which is equal to 50 ohms minus the resistance of R1 and R2, so we can find the combined resistance, R, of R1 and R2 as follows:

$$R = \frac{(50 - R) \times .005}{.05 - .005} =$$

$$\frac{.25 - .005R}{.045}$$

$$.045R = .25 - .005R$$

$$.05R = .25$$

$$R = 5 \text{ ohms.}$$

Now we know that R1 + R2 equals 5 ohms; since R1 equals 1 ohm, R2 must equal 4 ohms; and since the total of all three resistors equals 10 ohms, R3 must equal 5 ohms.

The ring shunt has two advantages over the circuit shown in Fig. 11. For one thing, the values of the resistors on the high ranges do not need to be as low. If we used the same basic 5-ma, 40-ohm meter in an arrangement like Fig. 11, we would have to have a resistor of only a fraction of an ohm on the 250-ma range. The other advantage is that the total resistance across the meter itself is the same on all ranges, and can therefore be used to provide damping.

MEASURING DC VOLTAGES

The meter in a voltmeter is actually a milliammeter or microammeter. The most commonly used meter in making dc voltage measurements is the d'Arsonval meter, which as you know, is a current-operated meter. Voltage is measured by sending current through a known resistance.

For example, if a 10,000-ohm resistor is connected across a source, and we connect a milliammeter in series with the resistance and it indicates that a current of 1 ma flows through it, you can calculate the voltage from Ohm's Law, $E = IR$. The voltage across the resistor must be $E = .001 \times 10{,}000 = 10$ volts. If we reduce the voltage, and the current drops to .5 milliamperes, (.0005 amps), we know the voltage must be

$$E = .0005 \times 10{,}000 = 5 \text{ volts}$$

Using this principle, a resistor, called a "multiplier resistor" is connected in series with a milliammeter and the combination is connected across the voltage source to be measured as shown in Fig. 13. The scale, of course, is calibrated to show the voltage rather than the current. We can do this because the current will depend directly on the voltage.

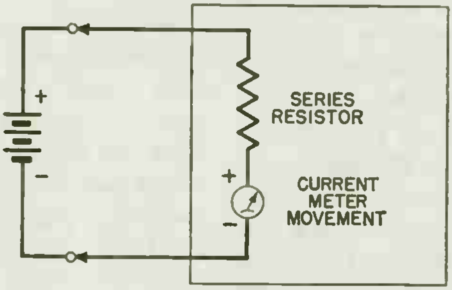


FIG. 13. How voltage can be measured by connecting a current meter and a series resistor across the source.

The value of resistance needed to be able to measure a certain voltage, depends upon the current range of the meter and the resistance of the meter itself, and upon the range of voltage to be measured. For example, suppose we have a 1-ma meter, and we want to use it to measure voltages from 0-1 volt. We find the value of resistance needed to limit the current flow in the meter circuit to 1 milliampere when the voltage across it is 1 volt by using Ohm's Law, $R = E/I$. The voltage range we want is 1 volt, and the current is 1 ma or .001 ampere, so we have $R = 1/.001 = 1000$ ohms. This is the total resistance in the circuit; it includes the resistance of the meter plus the resistance of the multiplier. In the example, if the meter has a resistance of 55 ohms, then the multiplier should have a resistance of 945 ohms.

Let's take another example, suppose we want to use a 50-microampere meter that has a resistance of 2000 ohms to measure voltage up to 10 volts. Using Ohm's Law to find the resistance we get:

$$R = \frac{10}{.00005} = 200{,}000 \text{ ohms.}$$

So the total resistance needed is 200,000 ohms. We can ignore the meter resistance in this example because it is so small, and simply connect a 200,000-ohm resistor in series with the meter. When 10 volts is applied to the series combination, the meter will read full scale. When 5 volts is applied, it will read half scale.

Voltmeter Loading. As we have said, the meter is always placed across the line to measure voltage, rather than in series with the line as when current is being measured. As you can see, a certain amount of current must flow through the meter and its series resistor. We say that the meter is loading the circuit. Because of this, in a low-current circuit, we must use a meter with high sensitivity, or it will not indicate circuit conditions accurately. For example, a 1-ma meter will draw 1 ma of current. If the normal circuit current is 1 ampere, the additional 1 ma, which is .001 amp, drawn by the meter will be an insignificant amount. However, if the normal circuit current is only half a milliampere, then the additional 1 milliampere that the meter draws represents an increase in the total circuit current of 200%. This increase in total current will upset a high-impedance circuit and the voltage indicated on the meter will be substantially less than the voltage that is normally present in the circuit.

An indication of how much a meter will load the circuit is given by the sensitivity of the meter. A meter with a high sensitivity requires less current to operate it than one with low sensitivity and hence loads the circuit less. For example, a 50-microampere meter is more sensitive than a 1-milliampere meter. It requires only 50 microamperes to give a full-scale deflection. A 1-milliampere meter, on the other hand, requires a current of 1 milliampere, which is 20 times 50 microamperes to give a full-scale reading. Thus, a voltmeter built with a 50-microampere meter and suitable multiplier resistors will be more sensitive and load the circuit only 1/20 as much as a similar voltmeter made with a 1-milliampere meter.

Instead of giving the sensitivity of meters in terms of the current needed for a full-scale meter deflection, manufacturer's rate them in ohms per volt. Let's see what this rating means.

A 1-milliampere meter requires a current of 1 milliampere to give a full-scale deflection. To convert this meter to a voltmeter with a full-scale range of 1 volt, we connect a multiplier resistor in series with the meter. The value of this resistor is

$$R = \frac{1}{.001} = 1000 \text{ ohms.}$$

If we wanted to make a 2-volt meter, we would need a resistor

$$R = \frac{2}{.001} = 2000 \text{ ohms.}$$

Notice that this is twice 1000 ohms. If we wanted a 10-volt meter we would need 10,000 ohms, which is ten times 1000 ohms, and if we wanted a 100-volt meter, we would need a 100,000-ohm multiplier, which is 100 times 1000 ohms. Thus we say the sensitivity of the meter is 1000 ohms per volt. From this figure we can immediately tell what the total resistance of the voltmeter is.

For example, if we have a 50-volt meter with a sensitivity of 1000 ohms per volt, we know that the total resistance of the meter plus its multiplier is 50 × 1000 ohms, which is 50,000 ohms. Notice that this figure is based on the full-scale range of the meter and not the voltage being measured. The resistance of the meter is 50,000 ohms whether the voltage being measured is 50 volts, 40 volts, 25 volts, or any other value.

You can determine the ohms-per-volt sensitivity of any meter if you know the current required for a full-scale deflection, or, if you know the ohms-per-volt sensitivity of a meter you can determine what current it draws at full scale.

For example, if we have a 50-microampere meter used in a voltmeter, its sensitivity is

$$R = \frac{1}{.00005} = 20{,}000 \text{ ohms.}$$

Thus its sensitivity is 20,000 ohms per volt. If the meter has a full-scale voltage of 150 volts, its total resistance will be 20,000 × 150 = 3,000,000 ohms.

If you have a meter rated at 10,000 ohms per volt and want to know what current is required for a full-scale deflection, you use Ohm's Law:

$$I = \frac{E}{R}$$

$$I = \frac{1}{10.000} = .0001 \text{ amps}$$
$$= 100 \text{ microamps.}$$

We can convert a one-milliampere full-scale d'Arsonval meter to a two-scale voltmeter by connecting the proper value multiplier resistors in series with the instrument, as shown in Fig. 14. Remember that to get an indication of 1 volt on a 1-milliampere meter, the series resistance must be 1000 ohms. If we wish to increase the full-scale reading to say 150 volts, we merely multiply 1000 by 150, which gives 150,000 ohms as the value of the series resistor between terminals A and B.

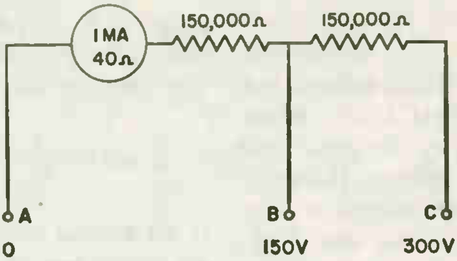


FIG. 14. How a 1-ma meter can be converted to a two-scale voltmeter.

To increase the full-scale reading to 300 volts, we add another 150,000-ohm resistor, giving a total of 300,000 ohms. In both cases, 1 milliampere of current flows through the meter, and the instrument has a sensitivity of 1000 ohms per volt on either scale.

In Fig. 14, the resistance of the 1-milliampere movement, 40 ohms, is negligible when compared with the value of the multiplier resistances. Thus, the meter resistance can be ignored. However, we would have to consider the meter resistance if we calculated the multiplier to make the meter read 1 volt full-scale deflection. The total meter circuit resistance would be 1000 ohms: 40 ohms in the meter, and 960 ohms in the multiplier.

Neglecting the meter resistance and using a 1000-ohm resistor would cause a 4% error in meter readings.

However, on the 150-volt range, neglecting the meter resistance and using a 150,000-ohm resistor would cause an error of only .02%. The percentage of error caused by neglecting the meter resistance will be approximately equal to the meter resistance divided by the multiplier resistance times 100. Although the percent of error decreases as the voltage range increases, the meter will always read low.

Meters with more sensitive movements will place less load on low-current circuits because of the much higher resistances used with them. For example, a .1-milliampere meter has a sensitivity of 10,000 ohms per volt. To extend its range to 150 volts, the resistor would be 10,000 × 150, or 1.5 megohms.

When measuring voltage, as when measuring current, if you are not sure what range to use, always use a high one, then switch to a lower one if the voltage to be measured is covered by the lower one.

Also, it would be very foolish to try to measure the output voltage of a power supply in a large transmitter or any other high-voltage source by holding the leads of a meter across it—you might even be electrocuted! If there is no permanent meter built in, and you must measure the voltage, first shut off the power. Then, discharge the filter capacitors, connect the meter across the output, turn on the power, and without touching the meter, read the voltage. Then, turn off the power, discharge the filter capacitors again, and disconnect the meter before turning the power back on.

PROTECTING THE METER

In communication circuits, special care must be taken to keep rf fields from affecting the meters. A strong field will induce rf currents in the meter wiring, which will affect the accuracy of the meter. High rf voltages may also cause the insulation to break down. This can be avoided in a dc meter in three ways: (1) connecting it so that it is at ground potential with respect to rf; (2) shunting it by an rf bypass capacitor; (3) putting an rf choke in series with it. Fig. 15A shows an example of the first method.

The meter is at the point of lowest rf potential in the cathode circuit. Although capacitor C1 does shunt rf currents to ground, it is not placed in the circuit specifically to protect the meter. Its primary function is to prevent degeneration in the circuit.

Fig. 15B shows the second method. This is used when a meter must be

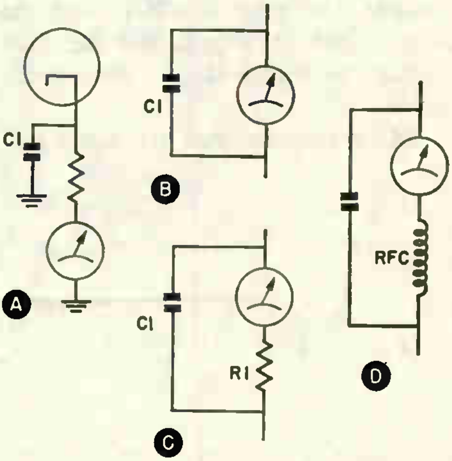


FIG. 15. How to protect a dc meter from strong rf fields.

placed in a lead that carries rf or af currents. A bypass capacitor having a low impedance compared to the meter impedance is used. The rf or af current follows the low-impedance path through the capacitor rather than the high-impedance path through the meter. This protection is sometimes increased by adding a resistor, as shown in Fig. 15C. The resistor, besides increasing the meter impedance, acts to damp out and prevent any resonance effects that might result from the parallel combination of the inductance of the meter coil and the capacitance of the bypass capacitor. Fig. 15D shows the third method. An rf choke is placed in series with the meter and within the circuit shunted by the bypass capacitor.

The bypass capacitor for rf circuits may be anywhere from .001 mfd to .01 mfd. For af circuits, the bypass capacitor should be .01 mfd to 1 mfd, depending upon the circuit. The size of the series resistor depends upon the current flowing in the circuit, but it is usually approximately equal to the meter resistance. The higher the resistor, the more it will protect the meter, but it should not be high enough to reduce the dc current too much.

DC voltmeters that are wired permanently into transmitter circuits are not put near rf fields. However, if you are making measurements with a portable instrument, you should be careful not to take your measurements where the meter can be affected by rf signals.

SUMMARY

Practically all meters used in communications work for measuring dc voltages and current have a basic d'Arsonval movement.

The range of a current meter can be extended by adding shunt resistors, the value depending upon the sensitivity of the meter and upon the current to be measured.

In a voltmeter, resistors called multipliers are added in series with the basic meter so the current through the resistor flows through the meter, and the combination is connected across the source to be measured. The meter scale is calibrated to show the voltage for the amount of current causing the pointer deflection.

For current measurements, the meter is always in series with the line; for voltage measurements, the meter is always across the line. When measuring either voltage or current always be sure to use a high enough range, or you may ruin the meter.

AC Measurements

The same basic meters can be used to measure alternating currents and voltages as are used to measure direct current and voltages. As you have learned, the magnetic vane meter and the dynamometer work on either ac or dc. Although they can be used with dc the d'Arsonval meter is so much superior for dc measurements that the magnetic vane type and the dynamometer are seldom used for dc measurements. The dynamometer is the most accurate of the meters for measuring alternating current and voltages, so it is often used as a standard for calibrating other instruments. The d'Arsonval meter can be used with copper oxide rectifiers to measure ac. This arrangement is primarily used in voltage measurements rather than current measurements. The d'Arsonval meter is used to measure alternating current by combining it with an arrangement called a thermocouple, which you will study in a minute.

MEASURING ALTERNATING CURRENT

In measuring alternating current, just as in measuring direct current, the meter is connected in series with the load. Again you must be careful to use a high enough range so you will not overload the meter.

AC meters are usually calibrated at some specific ac frequency. If the frequency at which you are taking measurements is too far removed from this, the readings will be somewhat inaccurate.

The range of an ac meter can be extended in the same way as that of a dc meter by adding a shunt resistance across the meter. The size resistance needed to extend a meter range to a given value is figured in the same way as the dc meters, using the same shunt formula.

The magnetic-vane meter and the dynamometer work directly on ac, but when the d'Arsonval meter is used, there must be some means of converting the ac to dc. One arrangement used particularly at rf frequencies is the thermocouple. Let's see how it works.

Thermocouples. The thermocouple works on the principle that when two dissimilar metals are joined and the junction is heated, there will be a dc voltage produced. The amplitude of this voltage depends upon the amount of temperature change at the junction. A sketch of a thermocouple junction is shown in Fig. 16A. Here two wires made of dissimilar metals are welded together to form a junction. The voltage produced at the junction can be measured between the other ends of the wires with a sensitive dc voltmeter.

Since current flowing through a resistance produces heat, we can get an indication of the amount of current flowing in a circuit by using a thermocouple junction along with a suitable meter as shown in Fig. 16B. The current to be measured is sent through a resistance wire or heater, producing heat. The junction of two dissimilar metal wires is brought near or actually welded to this heater. The other ends of the two wires are connected to a sensitive dc meter.

When current flows through the resistance, heat will be produced. The amount of heat produced will be proportional to the power dissipated in the resistance. Since the power dissipated in the resistance will be equal to I^2R, the heat will be proportional to the square of the current because the value of R remains constant. This heats the thermocouple junction, producing a dc voltage, which causes a dc current to flow through the thermocouple and through the meter.

Since the heat at the junction is proportional to the square of the current, and the generated dc is proportional to the heat, the meter will have what is called a square-law scale. Fig. 17 shows an example of a thermocouple meter with a square-law scale.

Square Law Meter Scales. Sometimes you'll have to use a standard dc milliammeter with a thermocouple or a square law meter. In this case the meter will be divided into equally squared divisions, and you can measure the current required for a full-scale deflection and then calculate the current for deflections less than full scale.

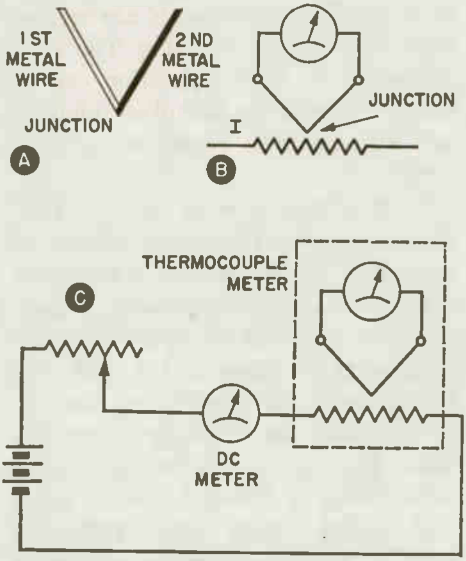
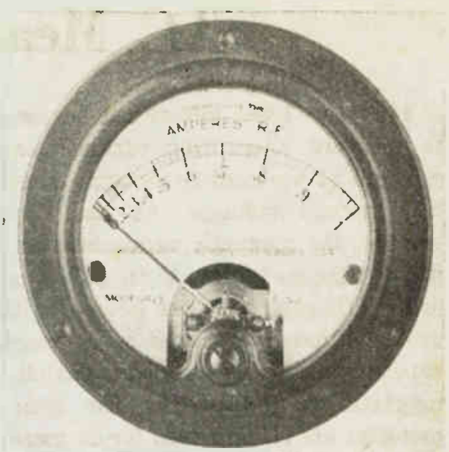


FIG. 16. How a thermocouple meter works.



Courtesy Weston Electrical Instrument Co.

FIG. 17. A thermocouple meter with a square-law scale.

For example, assume that you have a square law meter with the scale divided into 100 equally spaced "divisions." If the full-scale reading (meter deflection of 100 divisions) is 10 ma, what is the current which corresponds to half-scale deflection (50 divisions)? To determine the unknown current, use the formula:

$$\frac{D_a}{D_b} = \frac{I_a^2}{I_b^2}$$

where I_a is the unknown current, D_a is the deflection corresponding to it, I_b is the known current and D_b is the deflection corresponding to the known current. Using values, we have:

$$\frac{50}{100} = \frac{I^2}{10^2} \text{ or } \frac{50}{100} = \frac{I_a^2}{100}$$

When transposed, we get:

$$I_a^2 = \frac{50}{100} \times 100 = 50$$

Then,

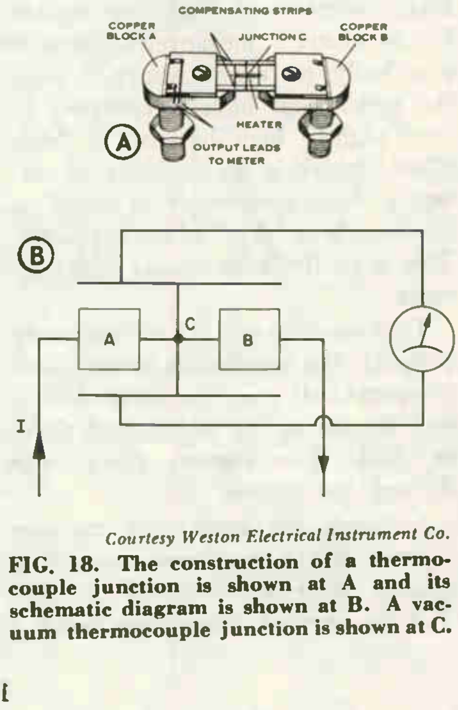
$$I = \sqrt{50}$$

which is approximately 7.1 ma.

You will remember that when we defined the ac ampere we said that an ac ampere is that ac current that will produce the same heating effect as one ampere of dc. Thus, since the relationship between ac and dc currents is based on the heating effect, we can calibrate a thermocouple-type meter with dc. A convenient circuit is shown in Fig. 16C. Here the dc current flow can be measured on a dc current meter and the reading on the meter connected across the thermocouple recorded. By adjusting the potentiometer the current can be varied so the entire thermocouple meter scale can be calibrated. Of course, thermocouple meters you buy come already calibrated, but this is how they are calibrated. Once they have been calibrated on dc they are quite accurate on ac even up into high radio frequencies. In fact, their accuracy is generally within 5% from dc up to 100 megacycles. In calibrating a thermocouple with dc, two sets of readings are usually taken, one with the current flowing in one direction and the other with it flowing in the opposite direction, and the readings are averaged.

The temperature difference between the hot junction and the free ends of the thermocouple element must not be influenced by surrounding temperature changes. To eliminate this possibility, the construction shown in Fig. 18A is used.

Fig. 18B shows the schematic diagram of this type of construction. There is a thin-walled tubular heater terminated in rather heavy copper blocks, A and B, which are so large they will not be heated by the heater. Current flowing through the heater will develop a temperature difference between the center of the heater and the blocks. The thermocouple junction C is on the center of the heater. The other ends of the wires are connected to two strips called "compensating strips." These strips are insulated from the blocks electrically by thin layers of mica, but connected to them thermally so the strips will be at the same temperature as the blocks. The heat capacity of the strips is such that the temperature difference between the ends of the thermocouple and the junction will always be the same as the temperature difference between the center of the heater and blocks A and B. Thus, if the temperature of the



Courtesy Weston Electrical Instrument Co.

FIG. 18. The construction of a thermocouple junction is shown at A and its schematic diagram is shown at B. A vacuum thermocouple junction is shown at C.

air surrounding the thermocouple changes, the temperature difference between the blocks and the center of the heater and between the junction and the ends of the thermocouple does not, so there will be no change in the potential developed by the thermocouple due to this change. Conductors are fastened to the ends of the compensating strips to conduct the potential developed by the thermocouple to the meter. If very small currents are to be measured, the thermocouple is enclosed in an evacuated glass envelope. This is designed to protect the elements from temperature changes which could be produced by warm air circulating around the thermocouple junction or the ends of the thermocouple.

Thermocouple meters are available in current ranges from less than 1 milliampere up to about 300 amperes. They are well suited for measuring radio frequency currents because of their accuracy at high frequencies. Up to about 2 megacycles, there is practically no error. Above 2 megs the meter does have a tendency to read slightly high because of "skin effect," which is the tendency of current at high frequencies to travel on the surface or "skin" of the conductor. This is particularly true at high currents.

To minimize skin effect and eddy currents, the conductors in the thermocouple unit are often made of thin-wall copper tubing plated with silver or gold. The current flows only through the plating.

Although the error may increase slightly as the frequency rises, it is usually below about 5% at 100 mc. The accuracy at frequencies below 2 mc may be as much as .5% at the temperature at which the meter was calibrated. Because of this accuracy at high frequencies, the thermocouple meter is often used as a standard for calibrating instruments at frequencies above those that can be measured on the dynamometer.

The meter used with a thermocouple must be very sensitive, because the output of the thermocouple unit may be only 15 millivolts.

Thermocouples in general must be handled with great care because they are delicate. You must avoid overloading a thermocouple because the heater is likely to burn out if subjected to more than a 40% overload.

MEASURING AC VOLTAGES

All three of the basic meter types can also be used to measure ac voltage. Just as for measuring dc voltage, a resistor is connected in series with the meter and the combination is connected across the source to be measured. The types of meters we have described in this lesson are seldom used to measure rf voltages. Such measurements will be discussed in a later lesson.

The magnetic vane meter is not suitable for most voltage measurements in communications circuits because it is difficult and costly to make a magnetic vane meter with a sensitivity better than about 5 ma. A voltmeter built around a milliammeter that required 5 ma for a full-scale deflection would have a sensitivity of only 200 ohms per volt. This would load many circuits to such an extent that the voltage reading on the meter would be much lower than the voltage normally present in the circuit.

A d'Arsonval meter can be used for ac voltage measurements by changing the current needed to operate the meter to dc. One common method of doing this is to use a copper oxide rectifier with the meter. We will study these now.

Using Rectifiers. The basic d'Arsonval meter can be used to measure ac voltages by connecting it to a single copper oxide rectifier as shown in Fig. 19A, or to a bridge circuit consisting of four copper-oxide rectifiers as shown in Fig. 19B. The rectifier consists of a number of copper discs. One side of each disc is covered with a film of copper oxide. Next to each disc is a lead washer, and the unit is held together under pressure in a clamp-like arrangement. Current will flow readily from the copper to the copper oxide, but will not flow readily in the opposite direction because the copper will readily give up its electrons but the copper oxide will not. The copper disc acts as the cathode of a rectifier, and the oxide acts as the anode. The lead disc is used as a means of contact with the copper oxide.

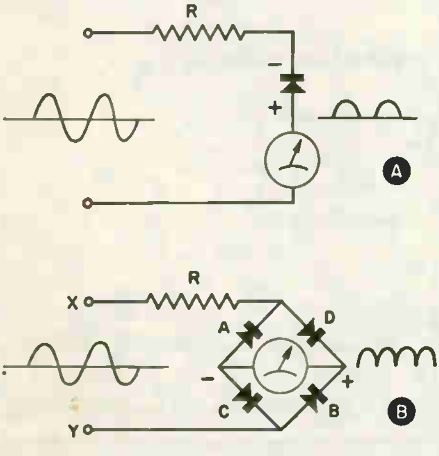


FIG. 19. A basic d'Arsonval meter can be used to measure ac voltages by connecting it to a single copper-oxide rectifier as at A, or to a bridge circuit at B.

The backward or reverse resistance of the unit to the flow of current in the opposite direction may be from 50 to 1500 times that of its forward resistance or rectifying direction.

Fig. 19A shows a single rectifier connected in series with the meter. This is a half-wave rectifier. Its output is a pulsating, direct current as shown by the waveform. The current flow is blocked during alternate half cycles.

In Fig. 19B, four copper-oxide rectifier units are connected in a full-wave bridge circuit. When point X is positive, current will flow from Y through rectifier C, through the meter from left to right, through rectifier D and resistor R to point X. When point Y is positive, current will flow from point X through resistor R and rectifier A, through the meter again from left to right, and through rectifier B to point Y.

The pointer of the meter cannot follow the pulsating direct current that appears at the input of the meter in either the full-wave or half-wave rectifier circuits. In the full-wave rectifier, the current that appears at the output of the rectifier is the average or .637 of the peak value. However, the scale is generally calibrated to read the rms or effective value of the voltage. In the half-wave rectifier the current at the output of the rectifier is only half of .637 or .318. Again the scale is calibrated to read the effective value of the voltage even though it is taken from the half cycle. The full-wave rectifier circuit is more commonly used than the half-wave circuit.

In the full-wave bridge circuit, both ac and dc are flowing simultaneously. The meter movement, however, is in that portion of the circuit where practically all the flow is in one direction. It is direct current resulting from having each alternate half of the sine wave flow through the meter element in the same direction.

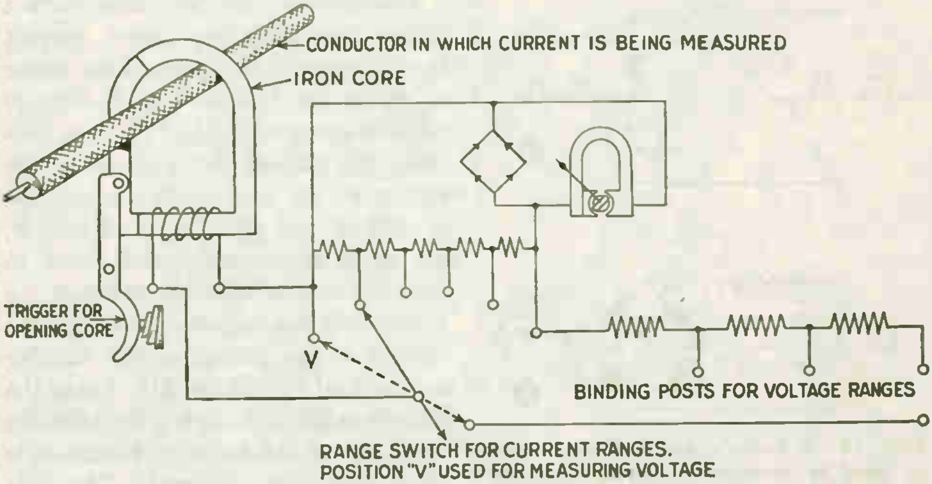
One of the advantages of the copper-oxide rectifier and d'Arsonval meter combinations for ac voltage measurements is that a very sensitive meter which takes little current from the source can be used. Another advantage is that the scale is linear. One disadvantage is known as frequency error. Because there is capacity between the oxide-coated sides and the non-oxide-coated sides of the discs in the rectifier unit, some current is bypassed, resulting in an error if the instrument is used at a frequency other than the one at which it was calibrated. Most instruments will read about 5% low for each 1000 cycles above the frequency for which the instrument is calibrated. The scale, for all practical purposes, is linear.

CLAMP-ON METER

We have mentioned several times that when current is being measured, the meter is connected in series with the line, and when voltage is being measured, the meter is connected across the line. However, there is a combination volt-ammeter that actually clamps around the line, so that the circuit need not be opened to take current measurements.

The diagram of a clamp-on meter is shown in Fig. 20. It consists of an iron-core that can be opened and clamped around the conductor carrying the current to be measured, with a coil wound around it connected to a d'Arsonval meter and bridge circuit.

The iron core and the coil form a transformer. The core is a one-turn



Courtesy Weston Electrical Instrument Co.

FIG. 20. A clamp-on meter.

primary, and the coil is the secondary.

The alternating current in the conductor produces a varying flux in the core. This in turn causes current to flow in the secondary, which is fed to the bridge circuit. The direct current output of the bridge actuates the meter movement. This type of meter is, of course, usable only with alternating current.

Both the current and the voltage range are usually wide, the current range may be as high as 1000 amperes, and the voltage range as high as 750 volts.

This instrument is a great aid in troubleshooting, especially to determine current flow taking place in a circuit in intermittent service, or to check running currents in motor circuits. It is also valuable in checking currents in three-phase circuits, which you will study later, to determine any unbalance that may exist between the phases, and in checking total input current against rated input current of a power supply. Care should be taken to see that the core laminations at the opening and hinged points are clean and sealed properly, otherwise possible obstruction at these points may cause erratic readings.

SUMMARY

The same basic meters are used for ac measurements as for dc measurements. When the d'Arsonval meter is used, the current fed to it must first be rectified. In current meters this is often done by means of a thermocouple. In voltage meters it is often done by means of copper-oxide rectifiers either singly or in a bridge circuit.

The meter is connected in series with the line to measure current and across the line to measure voltage.

When making measurements, it is always important to be sure to use a high enough range.

Resistance Measurements

Now let's see how the same basic current-operated meters can be used to measure resistance.

We know from Ohm's Law that $R = E/I$. Therefore, if we know the source voltage, and the current through a resistor, we can calculate the resistance. An ohmmeter does just this. It has its own source of dc voltage. When it is connected across a resistance, current flows through the resistance. The amount of current will be inversely proportional to the value of the resistance (the more resistance, the less current), and will determine the deflection of the pointer. The scale is calibrated to indicate directly the amount of resistance that will cause this amount of current flow. There are two general types of ohmmeter, the series type and the shunt type.

SERIES OHMMETER

The simplest type of direct-reading ohmmeter is shown in Fig. 21A. This ohmmeter is made up of a battery, a low-range milliammeter, and a combination of a fixed and a variable resistor, R1 and R2, in series.

The value of R1 plus R2 must be just enough so that with that particular battery voltage when the test leads of the instrument are touched together, making a complete circuit, the pointer of the current-operated meter movement will make a full-scale deflection. For example, if it is a 1-ma meter movement there must be 1 milliampere of current when the test leads are touched to each other. R2 is made adjustable because the battery voltage decreases with use and hence the resistance needed for a full-scale deflection will vary. Two resistors, one fixed and one variable are used to keep a minimum resistance in the circuit at all times. If you had only the variable resistance in the circuit and adjusted it so you had zero resistance in the circuit. such a high current would flow when you touched the test leads from the instrument together you could burn out the meter.

When an unknown resistance is to be measured, it is connected between the test probes as shown in Fig. 21B. Its resistance is added in series with R1 and R2, and the current will decrease accordingly, and there will be less deflection of the pointer. Since less deflection of the pointer means more resistance, the scale is printed with the zero at the right, which is the opposite of the current scale. A typical series-type ohmmeter scale is shown in Fig. 22.

To use this type of ohmmeter, the test leads are first shorted, and R2 is adjusted for a full-scale reading (zero on the Ohms scale). When the leads are connected across the unknown resistance, the current through the meter will be reduced because of the additional resistance. If the resistance being measured is equal to the resistance already in the meter circuit (the sum of the meter resistance and the resistance of R1 and R2), it will double the total resistance in the meter circuit, so the current will be cut in half, and the meter will read half scale. If the resistance being measured is less than the resistance in the meter circuit, the meter will read more than half scale. If the unknown resistance is greater than the resistance of the meter circuit, the meter will read less than half scale.

For example, the scale in Fig. 22 is for an ohmmeter with a 1-ma meter movement and a 3-volt battery. This means that the sum of R1 + R2 and the meter resistance will be 3000 ohms, because we need 3000 ohms in the circuit to limit the current to 1 ma with a 3-volt battery. We know this from Ohm's Law:

$$R = \frac{E}{I} = \frac{3}{.001} = 3000 \text{ ohms.}$$

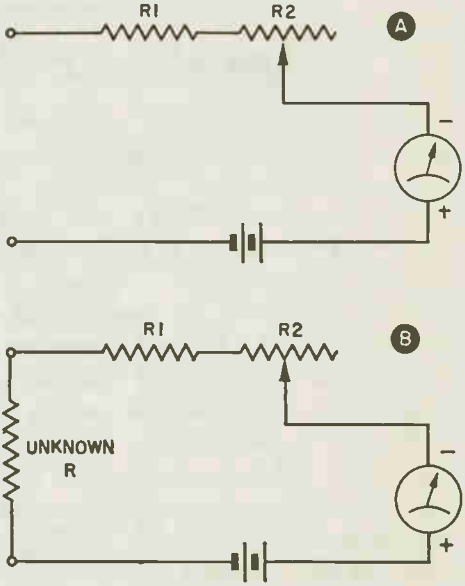


FIG. 21. A simple series-type ohmmeter.

This 3000 ohms might be made up of 100 ohms in the meter itself, a 1000-ohm potentiometer, R2, and a 1900-ohm resistor, R1. When the test leads are shorted so there is no additional resistance in the circuit, the meter will read full-scale (zero on the ohms scale). If a 3000-ohm resistor is connected between the leads, the total resistance will have doubled, the current will be cut in half, and the pointer will be at the center of the scale. As you can see, this is 3000 in Fig. 22. If the resistance being measured is 6000 ohms, the total resistance will have tripled, the current will be cut to one-third its full-scale value, and the pointer will be one-third of the way over. Thus, because of the relationship between the resistance and the current, zero resistance is at the right-hand end of the scale; 3000 ohms is represented by half the scale; the next 3000 ohms is represented by only one-sixth of the scale; the next 3000 ohms by only one-twelfth of the scale, etc.

FIG. 22. A scale for a series-type ohmmeter having a 3000-ohm center-scale value.

Higher resistance values can be measured with a series-type ohmmeter by using a higher battery voltage or a more sensitive meter. For example, if we used a 30-volt battery instead of a 3-volt battery with the 1-ma meter, then the resistance needed to limit the current to 1 ma when the test leads are shorted together would be

$$R = \frac{30}{.001} = 30{,}000 \text{ ohms.}$$

To reduce the current to .5 ma, we would need twice this resistance or 60,000 ohms. Thus, center scale on the meter would be 60,000 ohms minus 30,000 ohms (which is in the circuit at full scale) which is 30,000 ohms. The center of the scale on the ohmmeter would therefore be 30,000 ohms, ten times what it was with the 3-volt battery.

With a more sensitive meter we get the same results. Let's go back to the 3-volt battery and consider a 50-microamp meter. The resistance needed to limit the current will be:

$$R = \frac{3}{.00005} = 60{,}000 \text{ ohms.}$$

To reduce the current to half scale we would need an additional 60,000 ohms. Thus this meter would have a center scale resistance of 60,000 ohms.

Lower resistance values can be measured with a series-type meter by use of a shunt. Taking our original example of a 3-volt battery and a 1-ma meter, we can connect an additional resistor R3 in the circuit as shown in Fig. 23. Since R3 has a resistance of 333 ohms, which is 1/9 the resistance of $R1 + R2 + R_m$, nine times the current will flow through R3 that flows through the meter. Thus, with the test probes shorted together, the meter will read full scale, because 1 ma will flow through it and at the same time 9 ma will flow through R3. If we connect a resistance between the terminals that reduces the total current flow from 10 ma to 5 ma, we will get a half-scale reading on the meter, .5 ma of the current will

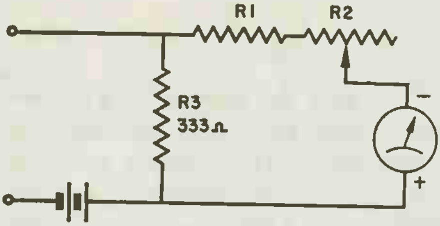


FIG. 23. Using a shunt with a series-type ohmmeter to measure lower resistances.

flow through the meter to give the half-scale reading, and the balance of the current, 4.5 ma, will flow through R3.

The resistance of R1 + R2 + R_m is 3000 ohms. This 3000 ohms is in parallel with 333 ohms. The resistance of the parallel combination is 300 ohms. With 300 ohms across the 3-volt battery, we get a total current of 10 ma which, as we said, gave us a full-scale meter reading. To cut the current in half, we need to double the resistance or add another 300 ohms between the test probes. Thus, with the shunt R3 added, center scale on the ohmmeter becomes 300 ohms. By adding a resistor that would permit still more current flow around the meter we could reduce the center scale resistance still further.

Some ohmmeters are arranged so that different values of shunt resistors can be switched into the circuit. The ohmmeter thus becomes a multi-range ohmmeter.

SHUNT OHMMETER

A different type of ohmmeter circuit is used when very low resistances are to be measured. This is the "shunt-type" shown in Fig. 24A. In this circuit, the milliammeter, the calibrating resistor R1, and the battery are connected in series and form a closed circuit even when the test leads are apart. The resistance of R1 must be just enough so that there will be enough current to cause a full-scale deflection of the meter pointer with the test leads apart (for a 1-ma meter, a 1-ma current). In actual practice R1 is made up of two resistors, a fixed resistor and a variable one to avoid the possibility of burning out the meter by setting the potentiometer so there is no resistance in series with the meter.

When the unknown resistance is connected between the test leads, it will be in parallel with the meter, as shown in Fig. 24B. This means that part of the current will flow through it, and part through the meter. If the

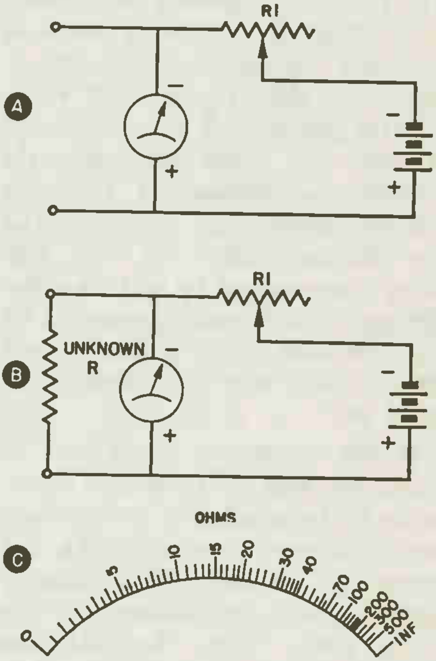


FIG. 24. A shunt-type ohmmeter circuit is shown at A and B, and the scale is shown at C.

resistance is high, most of the current will still flow through the meter, and the deflection will still be near full scale. If the resistance is low, most of the current will flow through it, not much will flow through the meter, and the deflection will be slight. If the resistance is exactly equal to the resistance of the meter itself, half the current will flow through it and half through the meter, and we will have a center-scale reading. As you can see, for low resistance values, the pointer would be at the left, and for high resistance values, it would be at the right. This means that zero would be at the left just as on a standard current scale.

A typical scale for a shunt-type ohmmeter is shown in Fig. 24C. The center-scale reading is 15, which means the resistance of the meter itself is 15 ohms. As you can see the scale is expanded at the low end just as the one for the series meter is.

The value of the resistance being measured would not appreciably affect the total resistance in the ohmmeter circuit, because the value of R1 would be so much larger than the value of the meter resistance, that for all practical purposes, it would determine the circuit current. For example, with a 1-ma meter and a 3-volt battery, the resistance of R1 plus the resistance of the meter would be 3000 ohms for full-scale deflection. Since the meter resistance is 15 ohms, R1 would be 2985 ohms. The resistance of the meter and the resistance being measured would vary from 0 to 15 ohms, depending upon the value of the resistance being measured. (Remember that the resistance of two resistors in parallel is always less than that of the smaller one). As you can see, this would not have any noticeable effect on the current drawn from the battery.

A word of caution about the use of this meter: Always turn it off when you are not using it, or you will drain the battery. You should get in the habit of switching it off after every measurement.

ACCURACY

The accuracy of any ohmmeter is limited by the stability of the battery terminal voltage. If the battery voltage is high, the meter will read low. If the battery voltage is low, the meter will read high. Practically all ohmmeters are designed to use batteries which are multiples of 1.5 volts; 1.5, 3.0, 4.5 volts, etc. Check the ohmmeter battery voltage occasionally to make sure your ohmmeter measurements will be reasonably accurate.

You can check the accuracy of the ohmmeter by measuring the value of a known resistance. A resistor with a tolerance of 1% is satisfactory. Choose a resistance value that will cause the ohmmeter pointer to indicate somewhere near the center of the ohmmeter scale.

The accuracy of most ohmmeters is only about 10% to 20%. That is, when the meter reads 100 ohms, the value of the resistance being measured may be anywhere between 80 and 120 ohms. However, this is usually as accurate as it needs to be for all practical purposes. If you must obtain a more accurate measurement, there are other instruments that can be used. You will study some of these instruments later.

THE MEGGER

Another resistance-measuring instrument you should become familiar with is the megohmmeter, or "megger," as it is called. As its name implies, it is used to measure very high resistance such as leakage in the insulation of cables, motor windings, transformers, and so forth.

Instead of a battery, it has a generator operated by a hand crank that generates about 500 volts. The meter is similar to a standard d'Arsonval meter, except it has two coils between the poles of the permanent magnet, wound on the same core, as shown in Fig. 25. Coil L1, which is called the *current coil*, is positioned so that when current flows through it, it will tend to move the pointer to the right (towards zero). Coil L2, which is called the *potential coil*, is positioned so that when current flows through it, it will move the pointer to the left (toward infinity).

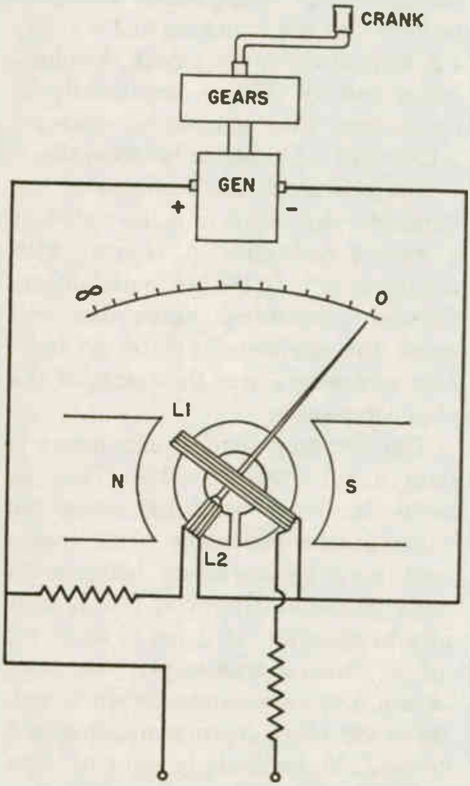


FIG. 25. How the "megger" is made.

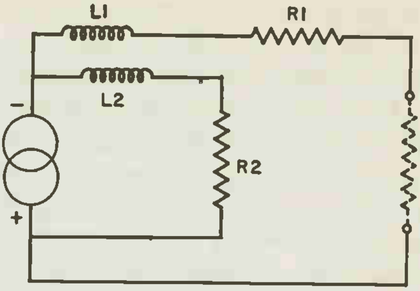


FIG. 26. Simplified schematic of the megger.

Fig. 26 shows a simplified schematic of the megger. The pointer on the megger is not restrained by springs so it is free to move to any position when the instrument is not in use. When you begin turning the hand crank the generator generates a voltage and as you can see, when nothing is connected across the terminals, the circuit will be open, and no current will flow through L1. However, current will flow through L2 and this current causes the pointer to swing to infinity. When a resistance is connected across the terminals, current will flow through L1, and this will tend to move the meter pointer towards zero. The current flowing through L1 will also tend to load the generator, which reduces the voltage and current through L2. This reduces the torque produced by L2 which has a further tendency to let the pointer move towards zero. How far it goes in this direction depends on how low the resistance is across the terminal. The lower the resistance, the more the pointer will move.

If there is any electrical path between the terminals, the meter will indicate it—up to hundreds of megohms.

For example, suppose you have a power transformer that has been subjected to undue moisture. Before placing it in operation you want to know if the moisture has caused leakage between the primary and the secondary. Connect the megger as shown in Fig. 27, and turn the crank. If there is any resistance between the primary and secondary it will be indicated on the meter scale. The design of the instrument is such that the speed of the crank has little effect on the reading as long as it is turned at a reasonable speed.

MULTIMETERS

Since the same basic meters can be used to measure current, voltage, and resistance, combination instruments, called multimeters can be designed that will measure all three. The same meter is used; it is connected in different ways by means of switches to measure current, voltage, and resistance. Multimeters are used for general maintenance and repair of electronic equipment. Fig. 28 shows the schematic diagram of such an instrument.

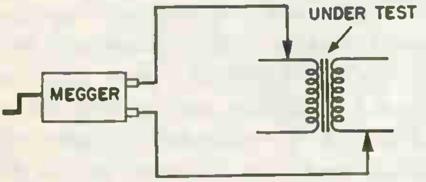


FIG. 27. How to test for leakage between transformer windings with a megger.

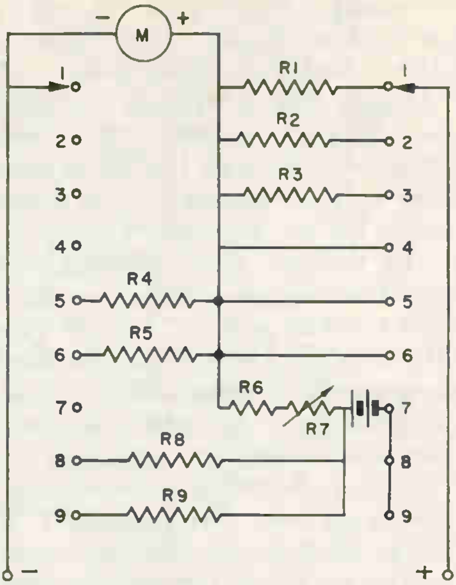


FIG. 28. Schematic diagram of a multimeter.

In the position shown, which we will call position 1, R1 is a voltage multiplier. It is in series with the meter. In position 2, R2 will be in series with the meter, and in position 3, R3 will be in series with the meter. If the meter is a 1-ma meter, by selecting R1 so its resistance plus the resistance of the meter is 1000 ohms, we could measure voltages up to 1 volt. By making the total resistance of the meter plus R2 equal to 10,000 ohms we could measure voltages up to ten volts in position 2, and by making R3 equal to 100,000 ohms we can measure voltages up to 100 volts in position 3.

In position 4 the meter is used as a 1-ma current meter. It is connected directly to the output terminals. In position 5, R4 is a shunt and will be connected directly across the meter terminals. In position 6, R5 will be a shunt across the meter terminals. If the resistance of the meter is 45 ohms, by making R4 equal to 5 ohms and R5 equal to .454 ohms we can measure currents up to 1 ma in position 4, up to 10 ma in position 5, and up to 100 ma in position 6.

In the last three positions, the meter is used as an ohmmeter. With a 3-volt battery and R6 + R7 plus the meter equal to 3000 ohms, we have a meter with a center scale resistance of 3000 ohms. In position 8, R8 is connected across the meter and R6 and R7. In position 9, R9 is connected across the meter and R6 and R7. If R8 is a 333-ohm resistor, the center scale resistance on this range becomes 300 ohms. By making R9 equal 30.3 ohms, the center scale resistance becomes 30 ohms.

Thus, with this arrangement we have three voltage, three current, and three resistance ranges. Additional ranges could be added by using a switch with more positions. Some of these positions could be for ac voltage measurements if we added a copper-oxide rectifier.

SUMMARY

The two main types of ohmmeters are the series type and the shunt type. Both use d'Arsonval meters. The series type has the zero at the right end of the scale; the shunt type has the zero at the left end of the scale. The shunt type is used to measure low resistance. Ohmmeters contain their own source of voltage, so the circuit in which measurements are being taken should be turned off.

An instrument called a "megger" is used to measure very high resistances. Instead of a battery, it has a 500-volt generator, and will measure resistances up to hundreds of megohms.

Current, voltage, and resistance meters are often combined in one instrument called a "multimeter."

Power Measurements

Power is the amount of electrical energy consumed in a circuit. It is measured in watts, kilowatts (thousands of watts), microwatts (millionths of a watt), or milliwatts (thousandths of a watt). In a circuit having only pure resistance, the power in watts is equal to the current in amperes multiplied by the voltage in volts, or $P = E \times I$. This is true in a dc circuit or in an ac circuit in which there is only resistance. In a circuit having inductance or capacity the phase angle between the voltage and the current must also be taken into account when figuring the power consumption. The phase angle is taken into account by multiplying the voltage and current by a figure known as the power factor, so the formula for power in an ac circuit is $P = E \times I \times PF$. The value of the power factor will be somewhere between zero and one. It is zero if the voltage and current are 90° out of phase, and one when the voltage and current are in phase. The power factor in an ac circuit is equal to the ratio of the resistance in the circuit to the impedance in the circuit. It is also equal to the cosine of the phase angle between the voltage and current.

Actually, you use this same formula for dc power, but since the power factor is always 1 in a dc circuit, it is ignored. Let's see how power is measured in dc circuits, in 60-cycle power-line circuits, in af circuits, and in rf circuits.

DC POWER MEASUREMENTS

It is easy to find the power in a dc circuit by connecting an ammeter in series with the circuit, and a voltmeter across it, then multiplying the indicated current by the indicated voltage. For example, if the voltage is 100 volts and the current is 10 amperes, the power consumed would be 1000 watts, or 1 kilowatt. (If this continued for 1 hour, we would say 1 kilowatt-hour of power had been consumed).

In making power measurements in this way, the position of the two meters in the circuit can make a difference. If they are connected as in Fig. 29A, the current drawn by the voltmeter flows through the ammeter. In a circuit where the current is low, this could add appreciably to the current indication, particularly if the voltmeter sensitivity is low. If the meters are connected as shown in Fig. 29B, the voltage indicated on the voltmeter will be slightly higher than the voltage across the load. If the current is very high, the drop across the ammeter may be enough to upset the calculation. At high currents the circuit at A should be used, at low currents, the one at B.

DC power can also be measured with a wattmeter, but it is usually simpler to measure it with a voltmeter and an ammeter.

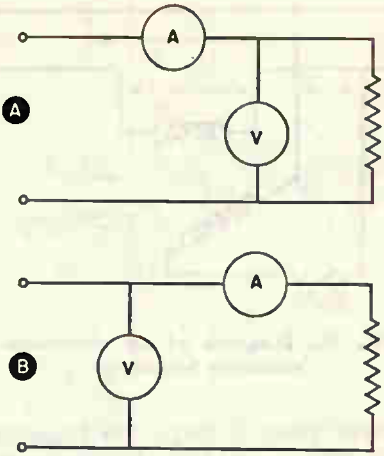


FIG. 29. Power can be measured by connecting an ammeter in series with the circuit, and a voltmeter across the circuit, then multiplying the readings. The arrangement at A is best for high currents, and the arrangement at B is best for low currents.

60-CYCLE POWER MEASUREMENTS

A wattmeter is generally used for measuring power in 60-cycle power line circuits. We cannot get the true power consumed by connecting a voltmeter and an ammeter into the circuit then multiplying the effective current by the effective voltage because we have not taken phase difference into consideration. The figure we would get by multiplying the effective current by the effective voltage is known as the apparent power and is expressed in volt-amperes.

A wattmeter takes the power factor into account. A dynamometer is the type of meter generally used as a wattmeter. Fig. 30 shows a schematic diagram of a wattmeter. The line

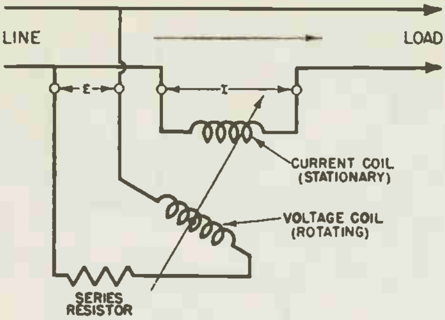


FIG. 30. Diagram of an electrodynamometer wattmeter.

current flows through the stationary coil. The movable coil is connected in series with a suitable resistance and connected across the line. The magnetic field of the stationary coil is proportional to the instantaneous current, and the magnetic field of the movable coil is proportional to the instantaneous voltage. The deflection of the pointer is proportional to the product of the magnetic fields. Since it is the instantaneous values of current and voltage that determine the deflection, it is an indication of true power.

Wattmeters are delicate instruments, and should be handled with care. They have maximum voltage and current ratings in addition to a maximum power rating. For example, a 500-watt meter should not be used to measure power of more than 500 watts. Also, if the meter is rated at a maximum voltage of 600 volts and a maximum current of 1.25 amps, you could overload the current coils by using it on a circuit when the voltage is 50 volts and the current 3 amps, even though the power in this circuit is only 150 watts. Similarly, you could overload the voltage coil by using the meter in a 1000-volt circuit when the current is .1 amp, even though the power is only 100 watts.

AF POWER MEASUREMENTS

Meters that are designed to measure the power output of audio-frequency devices such as audio amplifiers, radio receivers, etc. are designed to measure the voltage across a resistor. Since the voltage across a resistor and the current through it are in phase, the power factor will be 1, so the power will be directly proportional to the square of the voltage.

There are three general types of af power meters: the power output meter, the power level meter, and the VU meter.

Power Output Meter. The power output meter is a rectifier voltmeter with a resistor connected across it. The output from the device to be tested is applied across this resistor instead of to the usual load. The power dissipated in the resistor will be equal to $E^2 \div R$. Thus, if we know the resistance, we can determine the power by measuring the voltage across the resistance, squaring it, and dividing it by the resistance. Since the resistor is always the same, the meter can be calibrated directly in watts.

Power Level Meter. The power level meter is also a rectifier voltmeter, but it does not have a resistor built in across the meter. It must be connected across the load of the device under test. A high resistance voltmeter is used to place as little additional load on the circuit as possible.

This type of meter must always be connected across the same value of resistance for which it was designed, usually in communications work, 500 ohms. The power level meter is designed to indicate the ratio of output power to a certain reference level, and is therefore calibrated in decibels (db) rather than in watts.

A common reference level in communications work is 6 milliwatts of power into a 500-ohm load. This is called 0 db. Using the power equation $P = E^2 \div R$, we find that with 500 ohms and 6 milliwatts of power, the voltage is 1.73 volts. Therefore, by measuring the output voltage the meter can tell whether the power has gone above or below this reference level. If it is above, the meter indicates + db; if it is below, the meter indicates — db.

The advantage of this system is that it provides us with a convenient method of comparing different devices on a more or less common base.

For example, a manufacturer of a receiver may state in his specifications that the output of the receiver will be 0 db with a 100%-modulated input signal of 1 microvolt. This immediately provides us with a means of checking the receiver performance or comparing its rated sensitivity with that of another receiver.

It is important that you use this type of meter across the correct load impedance. Remember the meter is basically a voltmeter. It will indicate correctly in watts only when used across the load for which it was designed. For example, 1.73 volts across a 500-ohm load is 6 milliwatts, which we have set as zero db. Suppose we used this meter across a 10-ohm load. Now if the voltage is 1.73 volts, the meter, since it is a voltmeter, would indicate 0 db or 6 milliwatts. However, the actual power is $1.73^2 \div 10 = .3$ watt! Thus, to get an accurate reading with this instrument we must use it across the rated load of 500 ohms.

VU Meter. The VU meter is also used to indicate power ratios rather than watts of power. The unit used is called a volume unit or VU instead of a decibel, and the reference level is 1 milliwatt into 600 ohms. This is called 0 VU. With 1 milliwatt of power and 600 ohms of resistance, the voltage is .775 volts. If the voltage goes above this, the meter will indicate +VU, and if it goes below this, the meter will indicate —VU. Like the power level meter, it must be used across the correct load. These instruments are built using a special copper-oxide rectifier and an extremely sensitive meter. They are usually built right into the transmitter.

Fig. 31 shows a VU meter scale. It is only accurate in transmitters designed so that 100% modulation is obtained when the meter indicates 0 VU. The figures below the VU scale indicate the percent of modulation.

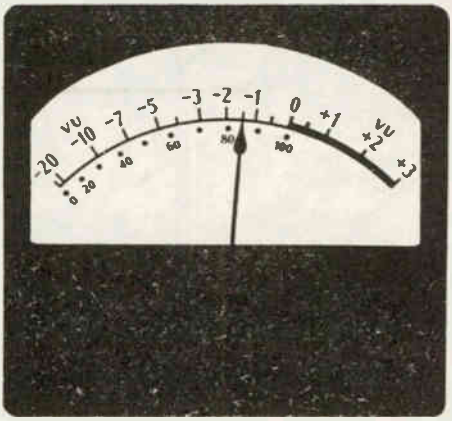


FIG. 31. A typical VU meter.

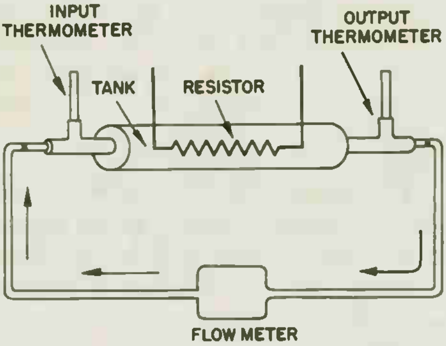


FIG. 32. How rf power can be measured without producing radiation.

RF POWER MEASUREMENTS

The radio frequency power output of a transmitter can be measured without actually producing radiation as shown in Fig. 32. Here a dummy load resistor is connected to the output circuit of the transmitter. This resistor is in a tank through which water is circulated to absorb the heat developed in the resistor. The water also goes through a flow meter that shows how much water flows through the unit in a given length of time. There are also thermometers that indicate the temperature of the water at the input and at the output of the tank.

Charts are provided with this type of measuring equipment so that you can calculate the power from the two temperatures and the water flow. This is called the calorimeter method of measuring power.

LOOKING AHEAD

In this lesson you have studied the three basic types of meters and learned how they can be used to measure current, voltage, resistance, and power. In later lessons you will learn about other types of instruments that use vacuum tubes in their circuits.

It is very important for you to understand how to use test equipment, because it is of little value unless you do.

Lesson Questions

Be sure to number your Answer Sheet 22CC.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of lessons before new ones can reach you.

1. What type of meter is generally used for dc measurements?
2. Give two reasons why the moving vane meter is not as widely used as the d'Arsonval meter.
3. Determine the resistance of the shunt needed to convert a 1-ma meter with a resistance of 100 ohms to a 5-ma meter.
4. If two ammeters connected in series with the same load, each indicate a current of 8 amps, what is the current flowing in the circuit?
5. What size multiplier resistor would you need to convert a 1-ma meter to a voltmeter with a full-scale voltage of 50 volts?
6. Find the sensitivity in ohms per volt of a voltmeter which uses a 10-microampere meter.
7. Why is a voltmeter with a high ohms-per-volt sensitivity more useful than one with a low sensitivity?
8. If the reading on a 50-volt voltmeter connected across a circuit is half-scale, indicating a voltage of 25 volts, and the meter sensitivity is 1000 ohms per volt, what is the total resistance of the meter and its multiplier?
9. Draw a schematic diagram of a series-connected ohmmeter.
10. If in a dc circuit a voltmeter connected across the load indicates 45 volts and an ammeter in series with the load indicates 7 amps, what is the power in the load?

THE VALUE OF REVIEW

Man has acquired so much new knowledge in recent years that it has become impossible for one person to know everything available about even a limited subject. Educational authorities realize this fact, and the colleges of today consider a man well-educated if he knows the elementary ideas *and knows where to find other information when he wants it.*

The field of radio and television has outgrown the memorizing ability of the human mind. Also, it is such a comprehensive field that occasionally you cannot recall important facts previously studied. Review is obviously needed.

Time spent in review several weeks or months after a book is studied will be far more profitable than an equivalent amount of extra time spent on the book initially, for your mind has then had a chance to file and store away the information secured from the first study. Each review results in more information being transferred from the textbook to your mind, and soon, with no conscious attempt to memorize, you will find yourself able to recall an amazing number of valuable facts.

J. M. Smith


nri

RADIO • TELEVISION • COMMUNICATIONS

ATTENUATORS, FILTERS, AND EQUALIZERS

29 CC

NATIONAL RADIO INSTITUTE • WASHINGTON, D. C.

ATTENUATORS, FILTERS, AND EQUALIZERS

29CC

STUDY SCHEDULE NO. 29

☐ 1. **Introduction** . . . . **Pages 1-2**

The differences between attenuators, filters, and equalizers are discussed.

☐ 2. **Impedance-Matching and Power Transfer** . . . . **Pages 2-6**

We take up methods of measuring power, and then go into impedance-matching.

☐ 3. **Resistive Pads and Attenuators** . . . . **Pages 6-21**

Here we take up simple attenuators, and symmetrical and non-symmetrical attenuators.

☐ 4. **Equalizers** . . . . **Pages 21-29**

You study line equalizers, pickup equalizers, and tape-system equalizers.

☐ 5. **Filters** . . . . **Pages 29-44**

We take up different types of filter circuits, and then go into filter design.

☐ 6. **Answer Lesson Questions.**

☐ 7. **Start Studying the Next Lesson.**

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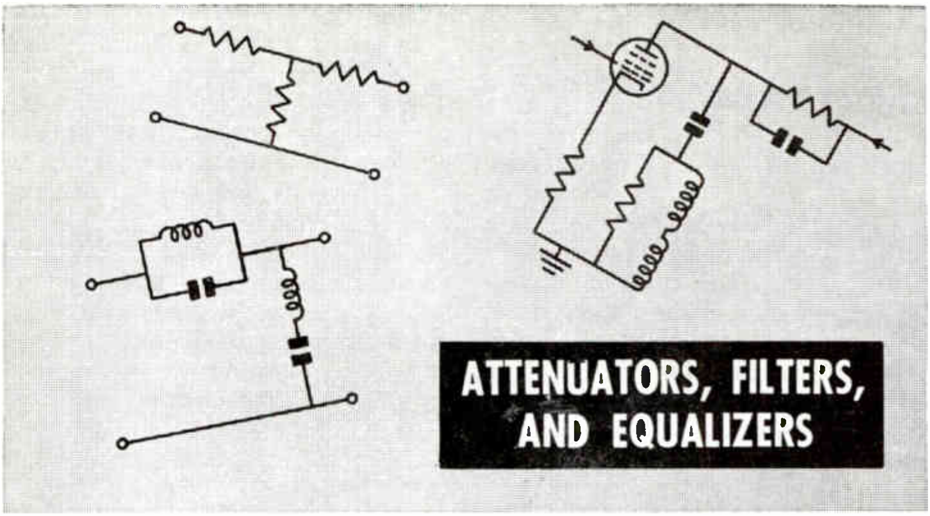


ATTENUATORS, FILTERS, AND EQUALIZERS

ATTENUATORS, filters, and equalizers are all basically classified as networks. A network is an arrangement of electronic components, usually resistances or reactances, designed to provide some special effect. Actually, every electronic circuit is a network of some sort. However, when an engineer or technician speaks of a network, he is usually referring to some special group of components within a circuit. Such a network might be anything from a simple arrangement of resistors used for impedance matching to a complex group of reactances providing frequency selection.

Networks of this sort will be found in every field of electronics. They provide an efficient method of controlling signal strength, noise reduction, and phase shift. They can select one particular control signal from a number of signals being transmitted simultaneously over the same control line. In fact, some type of special network will be found in all but the very simplest of circuits.

Networks can be classified into three general types: attenuators, equalizers, and filters.

Attenuators. An attenuator is a network consisting of pure resistance; its operation is independent of the frequency or the phase of the signal. Its effect on all signals is the same at all frequencies.

Filters. A filter is frequency-selective. A filter always contains reactances of some sort, and will respond to different frequencies in different ways. In addition, a filter will usually shift the phase of the signal in some way. By using the proper values of circuit components and arranging them in special ways, we can make networks that will have almost any desired effect on the signal as it passes through the circuit from the supply to the load. Filters are used in electronic equipment to pass certain frequencies and reject others. They are broadband devices in that they tend to respond to a certain band of frequencies rather than to a specific frequency.

Equalizers. Equalizers are used to correct for any undesired frequency discrimination or phase shift in other equipment or in connecting cables.

If these networks were perfect, each would do only the job it is intended to do. An attenuator would simply change the amplitude of the signal. A filter would pass a certain band of frequencies and reject all outside of this band. An equalizer would correct any undesired phase shift or frequency discrimination. Actually, leakage and stray capacitance cause each to do a little of all three. Although, in this lesson, we may speak of one of these networks as if it did its job and its job alone, you should remember that a certain proportion of undesired effects is unavoidable. The secret of successful design lies in holding these effects to a minimum. At video and rf frequencies, good shielding and the proper layout of the parts will help to prevent trouble caused by leakage. At audio frequencies, the coupling between the cores of the coils, and the coil resistance may become problems.

In earlier lessons, we learned about some of the simpler types of networks. These consisted of voltage dividers, power-supply filters, tuning circuits, and vacuum-tube coupling circuits. In this lesson, we will look at some of the more complex networks. We will learn to recognize some of the basic network configurations and their effect on a signal. We will discuss the advantages and disadvantages of the various filters and problems in designing practical filter circuits.

First, let's see what problems are involved in impedance-matching and power transfer.

Impedance-Matching and Power Transfer

In setting up and adjusting electronic equipment, impedance-matching between stages and efficient transfer of power from one stage to another or to an antenna are important problems. We can tell how effectively these problems have been solved by measuring either the signal power or the signal voltage at the input or output of the two stages and comparing the two values to see if there has been a gain or a loss.

UNITS OF MEASURE

In an earlier lesson, you learned about the unit of measurement called the decibel and how it is used to express the ratio between input and output power. You also learned that voltage ratios can be expressed in decibels, but only when the impedances across which the two voltage measurements are taken are equal.

There is another unit of measurement which you will run into from time to time called the "neper." This unit originated in Europe and differs from the decibel in that it is based upon a different system of logarithms. In computing decibels, we use the system of common logarithms, with the base 10. In computing nepers, the system used is known as the natural logarithm system in which the base is an odd number, 2.71828. One neper equals 8.686 db, and 1 db equals .1151 neper. This unit is not widely used in the United States, but you will find it in some textbooks and reference material.

POWER MEASUREMENTS

Decibel Meters. Decibel meters have been used to read the power in the line directly in db. These are ac voltmeters calibrated in db units, with the zero-power-level indication at about center scale. They are de-

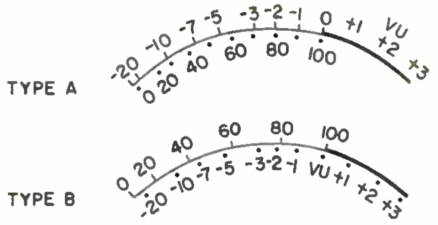


FIG. 1. Two types of VU meter scales.

signed to be connected across a specific value of impedance. Not all db meters have the same scale markings, damping, or zero levels. In the past, different services have used different values as the standard line-impedance across which the db meter is to be connected and have used different power levels as the zero reference level. Some have used .006-watt as the reference point, some .0125-watt, and others .001-watt. Some have used 500 ohms and some 600 ohms as standard line impedances.

When using a meter of this type, if the power in the line is more than the reference value, it produces a higher voltage across the line, and the meter reads to the right of the zero mark, showing a plus db reading. If the power is less than the reference value, the voltage is less, and the needle moves to less than center scale, indicating a minus db reading.

VU Meters. Since 1940, a standard type of power-level meter has been used in broadcast work and in many other audio applications. This is an ac volt-meter of the rectifier type called the volume unit or VU meter. Unlike db meters, all VU meters are built with identical characteristics. They are calibrated to read relative power levels when connected across a 600-ohm impedance line. The zero-reference level used is .001 watt (1 milliwatt). The VU meter is essentially a peak-reading meter, since with a relatively rapid pulse or steep wave, these meters rise to about 99% of the peak value very quickly, but fall off slowly.

VU meter scales are calibrated in plus or minus VU, and zero to 100% modulation. Two different types of VU meter scales are shown in Fig. 1.

The VU meter is designed to operate with a 3600-ohm external resistor as shown in Fig. 2. When the meter is connected across the line, it "sees" the 600-ohm source and load impedances in parallel. Thus, the impedance into which the meter is "looking" is 300 ohms. Since the meter has an impedance of 3900 ohms, an external 3600-ohm resistor is connected in series with the 300-ohm resistance of the parallel-connected source and load to match this impedance to that of the meter.

The resistor is not made an integral part of the meter because it may be

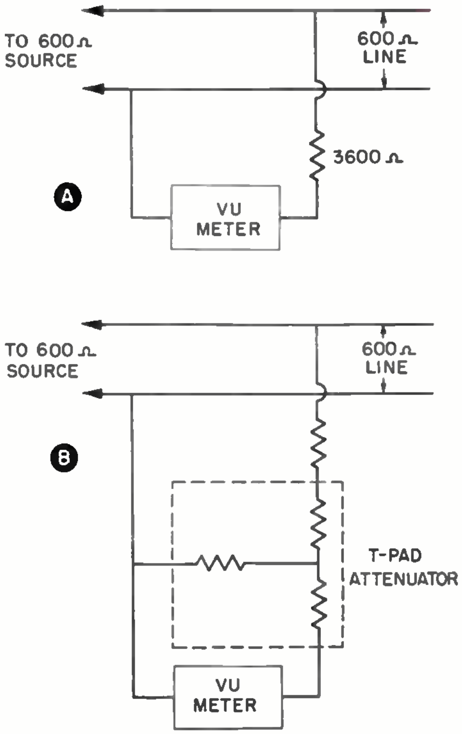


FIG. 2. A VU meter connected across a 600-ohm line is shown at A; a T-pad attenuator is added at B.

necessary to insert a T-pad attenuator in the meter circuit as shown in Fig. 2B. In broadcast work, a reading of zero VU or 100 on the percentage scale indicates 100% modulation. If the power required for 100% modulation is greater than the one milliwatt zero reference level, the meter would, of course, read farther upscale, and an attenuator called a T-pad is needed to make the meter indicate the correct percentage of modulation. Also, in some applications, the power in the line may be greater than the +3 VU at the high end of the meter scale. In these cases, a T-pad is needed to keep the meter from reading off-scale. Of course, in a case such as this, the loss introduced by the pad must be mentally added to the meter reading.

LOAD MATCHING

One of the most important considerations in the study of electronics is the transfer or transmission of power. In fact, the transmission and/or control of energy in the form of electrical power is the only purpose of any electronic system.

Let's look at some of the factors which affect this. In Fig. 3, we have shown a power source that develops an emf of 40 volts. Any source of power (generator, battery, or oscillator) has a certain amount of internal impedance, which consists of the distributed resistance, capacitance, and inductance in the source. We have assumed that our power source (let's call it a generator) has an internal impedance of 50Ω and have shown this as Z_I.

It is easy to see that the terminal voltage, E_T, is going to be equal to the emf minus the voltage across the internal impedance Z_I. The value of the voltage drop across Z_I will depend on the current flowing in the circuit as well as the value of Z_I, so the terminal voltage will vary with the current as long as the emf and Z_I remain constant. If the circuit is broken at the switch, no current will flow, there will be no voltage drop across Z_I, and E_T will be 40 volts. Now let's connect our generator to a load and see what happens.

If the selector switch is at A as shown, we will have a circuit consisting of Z_I which is equal to 50 ohms in series with Z_A, which is equal to 30 ohms. This gives us a total impedance of 80 ohms being supplied by our 40-volt emf. Through Ohm's Law ($I = E \div R$) we can determine that a current of .5 amp will flow in the circuit.

This means that we will have a voltage drop of 25 volts across Z_I, and a drop of 15 volts across Z_A. Therefore, although our power supply is actually generating 40 volts, 25 volts are dropped internally, and we have a terminal voltage, E_T, of only 15 volts.

If we look at the circuit from a power standpoint, we find that a total of

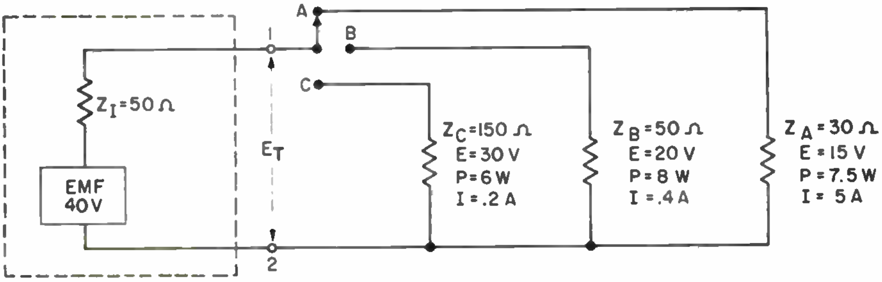


FIG. 3. Effect of load on power generation and transfer.

20 watts (40-volt emf x .5 amp) is developed by the power supply. However, 12.5 watts of this power (25 volts E_{Z1} x .5 amp) is wasted internally and only 7.5 watts is actually used by the load. This is obviously a very inefficient situation. If we have a load which consumes only 7.5 watts, it is a waste of equipment and energy to develop 20 watts to supply it.

Let's move the selector switch to Position B and see what effect a 50-ohm resistance has in our circuit. Now, our 40-volt emf will be feeding a total resistance of 100 ohms, and our circuit current will be .4 amp. We will have 20 volts dropped internally, leaving our terminal voltage at 20 volts. The total power developed will be 16 watts, and half of it, or 8 watts, will be consumed by the load. The other half will be wasted internally.

This is an improvement over the first circuit. First of all, we are developing a total power of only 16 watts, and we are getting 8 watts of this to our load. Thus, we have much better efficiency since we are wasting only 8 watts internally.

We actually have more power available in our external circuit with less total power generated. Notice that in this circuit the impedance of the load equals the impedance of the source; we say that they are "matched." Now, let's see if we can improve this still further by moving the selector switch to Position C.

In this position, the total impedance is 200 ohms, and the current will be .2 amp. The terminal voltage will be 30 volts, and the internal drop will be only 10 volts. The total power developed by the generator is only 8 watts. Of this, 6 watts is delivered to the load, while only 2 watts is wasted internally. Also, the voltage across the load has been increased. We have a much more efficient situation than we had before because we are wasting only 2 watts out of 8. However, we are delivering less power to the load than we were with circuit B when the load and source impedances were matched.

Thus, it is easy to see that a situation where the load impedance is much less than the source is always very inefficient and doesn't give much useful power. We can also see that we have the most power delivered to the load when the impedances are matched, but we do waste half of the power in the process. Further, the greatest efficiency exists when the load impedance is much larger than the source impedance although the actual power delivered to the load is less than when we have matched impedances. It is obvious that we will usually avoid having the load impedance less than the source impedance.

However, when it comes to a choice of having either maximum power with matched impedances or high efficiency with proper mismatching, we have to consider the specific application. For example, consider the circuit shown in Fig 4A, where the impedances are mismatched. If a large amount of power is required to operate the 450-ohm load, efficiency will be the most important. Let's assume that we have a large power requirement and the emf of the power source equals 10 kv. At 10 kv, 20 amperes of current will flow to the load, and a total power of 200 kw will be developed. Of this 200 kw, 20 kw will be wasted internally and 180 kw will be consumed in the load.

In the circuit of Fig. 4B we have shown the same load, but have matched the impedances. Notice that we have not shown the impedance matching system, but have just represented it by changing the value of the load resistance. In this circuit we would get more power to the load but the energy wasted would be tremendous. Our 10 kv emf would give 100 amps of current and the total power

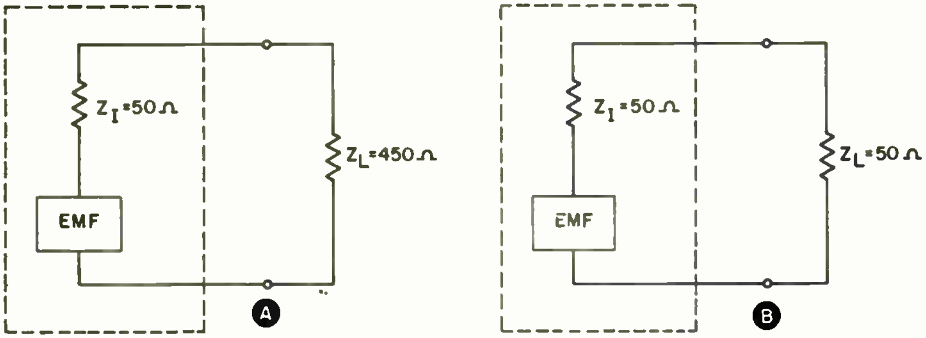


FIG. 4. Greatest efficiency with mismatched impedances, A; greatest power transfer with matched impedances, B.

developed would be 1000 kw. Of this, 500 kw would be wasted internally and 500 kw would be consumed by the load. Although we would have 320 kw more power available to do work than we had available with the mismatched impedances in Fig. 4A, we would waste 480 kw more in order to get it. The cost of producing this extra wasted energy would make it impractical to match impedances. In addition, the cost of equipment capable of handling 100 amperes of current would be much greater than that needed to handle 20 amperes. Thus, impedance matching becomes too expensive to be practical when large amounts of power must be handled.

In communications and control circuits, however, extremely small amounts of power are used, and power waste is not so expensive. Here, the important consideration is getting enough of the available power to the load for the equipment to operate properly. Often the available power is so low that unless the maximum amount is transferred to the load, the equipment will operate poorly or not at all.

For example, a speaker or speaker system must be matched to the output of the amplifier or it may not receive sufficient energy to operate properly. Similarly, a microphone must be matched to the input circuit of an amplifier or the losses will be severe.

Now that we have seen the problems involved in transferring power, let's look at the networks used to do so.

Resistive Pads and Attenuators

Resistive pads and attenuators are used to reduce or control signal levels, to match impedances, and to reduce the inductive effect of transformers coupled together through a line. Usually, they are used to reduce signal levels, to match impedances, or both.

SIMPLE ATTENUATORS

To see how an attenuator can introduce a loss without causing an impedance mismatch, it is best to examine some simple circuits. In Fig. 5A, we have a power source having a constant emf of 40 volts and an internal impedance of 50 ohms supplying power to a resistive load of 50 ohms. The load and source are matched and the power delivered to the load is 8 watts.

Suppose we want to reduce the power delivered to the load from 8 watts to 4 watts. We can do this by inserting a 43-ohm resistor in series with the load as shown in Fig. 5B. This makes a total impedance in the circuit of 143 ohms (50+50+43). The current is then .28 ampere (40÷143) and the voltage across the load is 14 volts (.28 x 50). This means the power delivered to the load is 4 watts (.28 x .28 x 50).

We can also reduce the power to 4 watts by adding a 58-ohm resistor in parallel with the load as shown in Fig. 5C. The impedance of the parallel combination will be 27 ohms, and the total impedance in the circuit will be 77 ohms (50+27). The circuit current will be .52 ampere, dividing through the parallel combination so that .28 ampere flows through the load. The voltage across the source impedance will be 26 volts (50 x .52), leaving 14 volts across the parallel combination (40—26). This means the power delivered to the load will again be 4 watts (.28 x .28 x 50).

In each case, we have delivered 4 watts to the load. However, the impedance match is destroyed in both cases. With the series resistor, in Fig. 5B, the impedance looking into the external circuit from terminals 1 and 2 is now 93 ohms (43 ohms and 50 ohms in series). With the parallel resistor, in Fig. 5C, the impedance seen looking into the circuit from terminals 1 and 2 is 27 ohms (50 ohms and 58 ohms in parallel).

Now, let us see if we can reduce the power delivered to the load from 8 watts to 4 watts and still keep the load matched to the source. Look at Fig. 5D. Here we have a 116-ohm resistor in parallel with the load, giving us a total impedance of 35 ohms for the parallel part of the circuit, and a 15-ohm resistor in series with the 35 ohms offered by the parallel combination. Now, the total impedance of the combination is 50 ohms, the total imped-

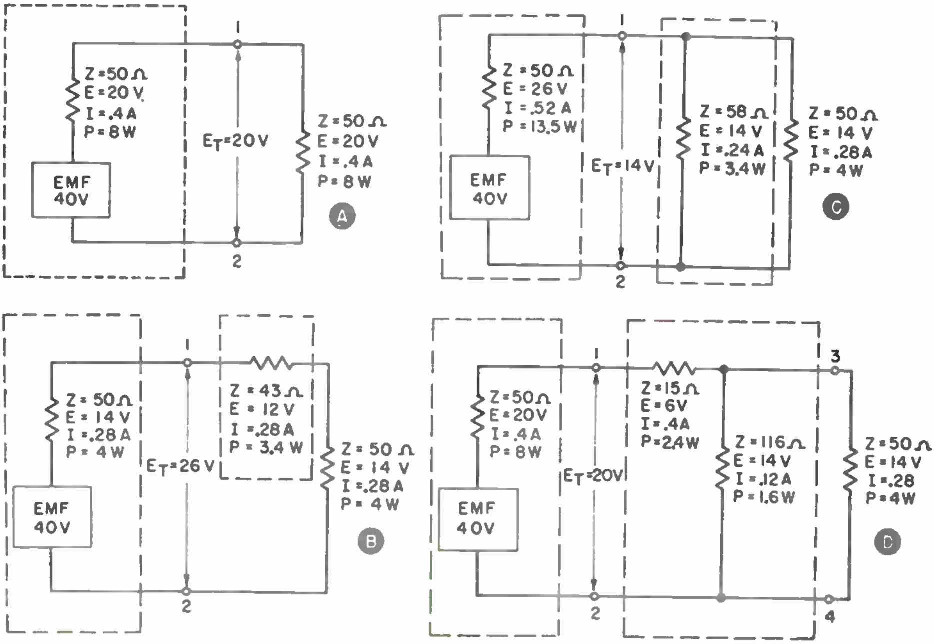


FIG. 5. Effect of dropping resistor on impedance match.

ance in the circuit is 100 ohms (50+50) as in Fig. 5A. The voltage across the load will be 14 volts, the current through it will be .28 ampere, and the power to it will be 4 watts. The total impedance as seen looking into terminals 1 and 2 is still 50 ohms. Thus, the load is still matched to the source even though the power in the load has been reduced to 4 watts.

A simple attenuator such as this that consists of one series resistance and one parallel resistance such as those we have been discussing is called an L pad.

The L Pad. Although the L pad is a definite improvement over a single resistance, it has one major disadvantage. This is the fact that it is unsymmetrical. In other words, it does not have the same impedance at both ends.

Up until now, this has not concerned us because we have been concerned only with matching a load to a source. However, in a perfect impedance match this is not enough. We do not have a perfect match unless the source sees exactly the same impedance looking towards the load as the load will see looking back toward the source.

Looking at the circuits shown in Fig. 6, you will see what we mean by this. In Fig. 6A, when the source looks into the circuit it sees an impedance of 50 ohms. In addition, if we look back into the circuit from the load we also see an impedance of 50 ohms. This is considered to be a perfect impedance match because the load sees exactly the same impedance looking toward the source as the source sees looking toward the load.

Now, let's put an L pad in the circuit as shown in Fig. 6B and see what we have. First, let's look into the circuit toward the load from terminals 1 and 2. Doing this, we see an impedance of 25 ohms in series with the parallel branch containing two 50-ohm resistors, whose combined resistance is 25 ohms. This gives us a total impedance of 50 ohms, which is equal to the source impedance, and we say that the load is matched to the source.

However, if we look back into the circuit towards the source from terminals 3 and 4, we do not see the same impedance. Now, we see an impedance of 50 ohms in parallel with an impedance of 75 ohms. This is a combined impedance of 30 ohms and does not equal the load impedance of 50 ohms. Thus, our L pad matches the load to the source, but does not match the source to the load.

Since an L pad is unsymmetrical, it cannot be used to provide a perfect impedance match between two equal impedances. However, it is often used to provide a match for two unequal impedances. Fig. 7 shows a circuit where a 50-ohm load and a 70-ohm

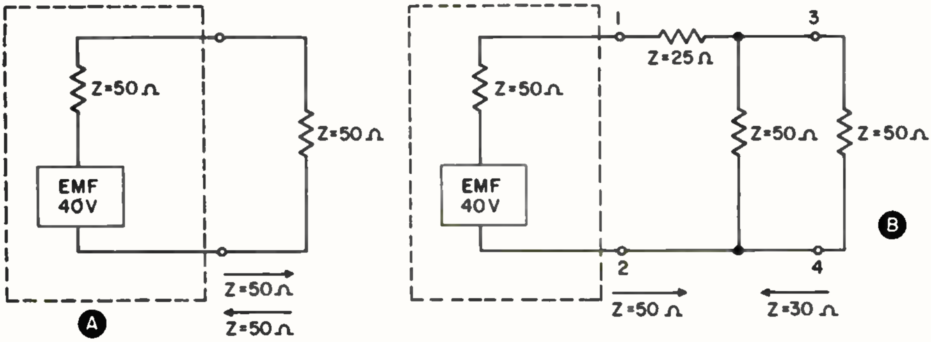


FIG. 6. Effect of unsymmetrical section on impedance match.

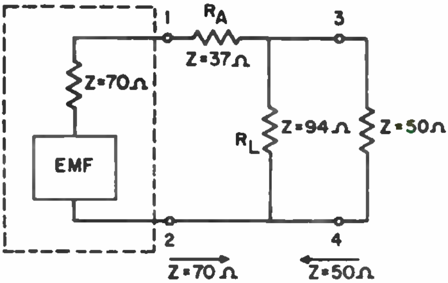


FIG. 7. Using L pad to match unequal impedances.

source have been matched by using an L pad.

Looking into the load from terminals 1 and 2, we see an impedance of approximately 70 ohms (37 ohms in series with the parallel combination of 94 ohms and 50 ohms). Looking back toward the load from the terminals 3 and 4, we see an impedance of almost exactly 50 ohms (94 ohms in parallel with the series combination of 70 and 37 ohms). Of course, the L pad always introduces a loss in the circuit and is not used to match impedance unless the loss can be tolerated or is actually desirable.

Minimum-Loss Matching Pads. By using two fairly simple formulas, we can compute the resistances for an impedance-matching L pad that will introduce the smallest possible loss. To find the value of the series or arm resistance of the pad, we use the following formula:

$$R_A = Z_I\sqrt{1 - \frac{Z_O}{Z_I}}$$

In this formula, R_A = arm resistance; Z_I = source or input impedance; and Z_O = load or output impedance.

To find the value of the parallel or leg resistor, we use the formula:

$$R_L = \frac{Z_O}{\sqrt{1 - \frac{Z_O}{Z_I}}}$$

Here, R_L = leg resistor, Z_I = source or input impedance, and Z_O = load or output impedance as before.

Let's use these two formulas to see if the L pad we used in Fig. 7 provides the smallest possible loss. In this circuit, our input impedance is 70 ohms and the output impedance is 50 ohms. Substituting these values in the formula for obtaining the arm resistance, we get:

$$R_A = Z_I\sqrt{1 - \frac{Z_O}{Z_I}}$$

$$= 70\sqrt{1 - \frac{50}{70}}$$

$$= 70\sqrt{1 - .72}$$

$$= 70\sqrt{.28}$$

$$= 70 \times .53$$

$$= 37\ \Omega$$

From this, we can see that the 37-ohm arm resistance which we used in the circuit is correct for the arm value of a minimum-loss pad.

To find the correct leg value, we substitute our 70-ohm input impedance, and our 50-ohm output impedance in the formula for finding R_L:

$$R_L = \frac{Z_O}{\sqrt{1 - \frac{Z_O}{Z_I}}}$$

$$= \frac{50}{\sqrt{1 - \frac{50}{70}}}$$

$$= \frac{50}{\sqrt{1 - .71}}$$

$$= \frac{50}{\sqrt{.29}}$$

$$= \frac{50}{.54}$$

$$= 92.5\ \Omega$$

This is equal to the leg resistor that we used in the circuit, so we know that the L pad used in Fig. 7 not only matches impedances, but it also introduces the least possible loss for a matching pad. Remember, the two formulas given here are used only to determine the values of resistance for use in a minimum-loss matching pad.

If we are going to design an impedance-matching pad, we will also be interested in knowing just how much attenuation will be introduced by our minimum-loss pad. So far in our discussion of impedance matching and attenuation, we have compared the power delivered to the load with the total power developed by our source. To do this, we have completely analyzed each circuit component as to impedance, voltage, current, and power so that you could actually see what happened to the power and where and why it happened. The amount of the losses provided by our attenuator was rated in watts. Although this is a good approach for purposes of analysis, there is a much simpler way of evaluating attenuation.

Since attenuators are so much a part of communications systems where the decibel is commonly used to express performance, it is logical that the decibel has come to be used as a measure of attenuation. Actually, the decibel is a very convenient unit for use with attenuators because we are concerned with power ratios. As we learned in an earlier lesson, the amount of change in decibels in a circuit is equal to 10 times the logarithm of the ratio of the input power and the output power. Thus, the attenuation or loss in a circuit in decibels can be found with the formula:

$$\text{db} = 10 \log \frac{P_I}{P_O}$$

This formula can be applied to any attenuator quite easily when the power in the circuit is known. However, instead of computing the necessary circuit values to obtain the power ratios in Fig. 7, we can use a more direct formula. This formula uses the input and output impedances directly, and can be used to determine the attenuation in decibels that will be introduced by any minimum-loss pad. In this formula, the loss in decibels equals:

$$\text{db} = 10 \log \left(\sqrt{\frac{Z_I}{Z_O}} + \sqrt{\frac{Z_I}{Z_O} - 1} \right)^2,$$

where Z_I = input impedance and Z_O = output impedance.

Let's apply this to the circuit in Fig. 7 to see how much attenuation our minimum-loss pad will introduce. Substituting in the equation, we have:

$$\begin{aligned}
\text{db} &= 10 \log \left(\sqrt{\frac{70}{50}} + \sqrt{\frac{70}{50} - 1} \right)^2 \\
&= 10 \log (\sqrt{1.4} + \sqrt{1.4 - 1})^2 \\
&= 10 \log (\sqrt{1.4} + \sqrt{.4})^2 \\
&= 10 \log (1.18 + .63)^2 \\
&= 10 \log (1.81)^2 \\
&= 10 \log 3.27 \\
&= 10 \times .5145 \\
&= 5.1 \text{ db loss}
\end{aligned}$$

Thus, the minimum loss possible in an impedance-matching pad for the circuit shown in Fig. 7 is 5.1 db. We have already discovered the proper values of arm and leg resistance for this pad.

SYMMETRICAL PADS

Symmetrical attenuators are similar to L pads except that they have either an extra series arm or an extra leg resistor.

The T Pad. Fig. 8 shows one of the most common types of symmetrical attenuators. This type of attenuator is usually called a T pad because the component resistors are arranged in the schematic so that they form the letter T.

As you can see, the impedances are perfectly matched because the load sees the same impedance looking towards the source from terminals 3 and 4 as the source sees looking into the load from terminals 1 and 2.

T pads can be designed to introduce any desired amount of attenuation. Let's use the circuit shown in Fig. 8 as an example and see what values we need in the T pad. First of all, the power input is 40 watts, and we want a power output of only 1 watt. Using our formula we find that:

$$\text{db} = 10 \log \frac{P_I}{P_O}$$

$$= 10 \log \frac{40}{1}$$

$$= 10 \log 40$$

$$= 10 \times 1.6021$$

$$= 16 \text{ db}$$

Now we must find the reduction factor K from the following formula:

$$K = \log^{-1} \frac{\text{db}}{20}$$

The symbol "$\log^{-1}$" is called an antilog, which means that our answer will be the number whose logarithm is $\frac{\text{db}}{20}$. Substituting our desired attenuation of 16 decibels in the formula, we find:

$$K = \log^{-1} \frac{16}{20} = \log^{-1} .8$$

Now from our log tables, we find that the number which has .8 for a logarithm is 6.31. Thus, our reduction factor K equals 6.31.

Next, we use the reduction factor K in two formulas. The first one will give us a multiplying factor for the arms, and the second will give us a multiplying factor for the leg. Multiplying these by either the source or the load impedance will give us the values for the arm and leg resistors.

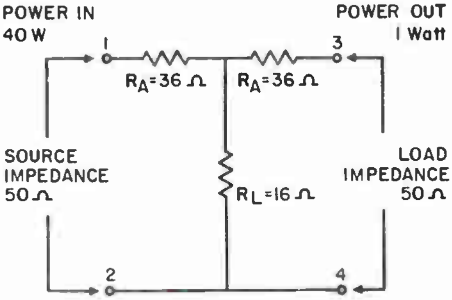


FIG. 8. T pad providing 16-db attenuation.

The formula for the arm factor is:

$$A = \frac{K - 1}{K + 1}$$

Substituting the value of K, which is 6.31 in this formula, we get:

$$A = \frac{6.31 - 1}{6.31 + 1}$$

$$= \frac{5.31}{7.31} = .72$$

Now, by multiplying our 50-ohm impedance by the arm factor A, we find the value of the arm resistors:

$$R_A = AZ = .72 \times 50 = 36\ \Omega$$

Thus, both arm resistors of the T pad must be equal to 36 ohms to give us an attenuation of 16 decibels while maintaining an impedance match between a 50-ohm source and a 50-ohm load.

The formula for the leg factor is:

$$L = \frac{2K}{K^2 - 1}$$

$$= \frac{2 \times 6.31}{6.31^2 - 1}$$

$$= \frac{12.62}{39.8 - 1}$$

$$= \frac{12.62}{38.8}$$

$$= .325$$

Our leg resistor equals:

$$R_L = LZ$$

$$= .325 \times 50$$

$$= 16\ \Omega$$

The resistance values for any T pad giving any desired value of attenuation between two equal impedances may be obtained using these formulas. Because of their importance in attenuator design, we will list them again.

Attenuation in db: $\text{db} = 10 \log \frac{P_I}{P_O}$

Reduction factor K: $K = \log^{-1} \frac{\text{db}}{20}$

Arm factor A: $A = \frac{K - 1}{K + 1}$

Leg factor L: $L = \frac{2K}{K^2 - 1}$

Arm resistors R_A: $R_A = AZ$

Leg resistor R_L: $R_L = LZ$

For convenience in designing attenuators, the multiplying factors for many different values of attenuation have been worked out in the form of tables. Although these tables do not give the values for arm and leg factors for all possible values of attenuation, they are very handy for designing most attenuators. These tables can be found in many reference books.

Attenuation db	Arm factor A	Leg factor L
0	0	∞
1	0.061	8.07
2	.115	4.27
3	.173	2.78
4	.227	2.07
5	.280	1.64
6	.333	1.33
7	.382	1.11
8	.432	0.942
9	.476	.812
10	.520	.700
20	.818	.202
30	.939	.0632
40	.980	.0200

FIG. 9. Table of multiplying factors for the design of any T pad.

A typical example giving the attenuation in decibels and the arm and leg factors is shown in Fig. 9. To use the table, we simply look down the attenuation column until we find the desired loss value. Then we follow across the table to find the arm factor and the leg factor to use with the impedance of our particular circuit in order to compute our arm and leg resistance values.

The π Pad. Another type of symmetrical attenuator is shown in Fig. 10. This is call a pi pad because the component resistances are arranged like the Greek letter π. The π pad in Fig. 10 is like the T pad shown in Fig. 8 in that it has an attenuation loss of 16 db and 50-ohm input and output impedance.

Since the pi pad and the T pad have identical behavior, we can expect a definite numerical relationship between them. We can, for example, set up a pi network like the one shown in Fig. 10 and determine the various resistance values by using the A and L factors that we derived while designing our T network. However, we must use them in a different way, as you will see.

The resistance of the arm of the pi pad is equal to the impedance Z divided by the T pad leg factor L. Similarly, each leg of the pi pad is equal to the impedance Z divided by the T pad arm factor A. In equation form these are:

$$\pi \text{ pad: } R_A = Z/L$$

$$\pi \text{ pad: } R_L = Z/A$$

It should be noted that the factors A and L are exactly the same as those used for the T pad design and are computed the same as before. However, in the pi pad the factors are used for division instead of multiplication, and L is used to find R_A, and A is used to find R_L.

Now let's compute the resistance values of the pi pad components shown in Fig. 10. Our desired attenuation is 16 db, and the source and load impedances are 50 ohms. This is the same requirement that we had in the circuit shown in Fig. 8, so we can use the same A and L factors that we previously computed. For our pi-pad arm, we use the formula:

$$R_A = Z/L$$

$$= \frac{50}{.325} = 154\ \Omega$$

Our leg resistors are found from the formula:

$$R_L = Z/A$$

$$= \frac{50}{.72}$$

$$= 70\ \Omega$$

Thus, our two legs must be 70 ohms, and our arm 154 ohms to provide the same effect with a pi pad as we had with the T pad shown in Fig. 8.

The table shown in Fig. 9 can also be used to construct pi pads. Just remember to divide the impedance by A to find R_L and by L to find R_A. In ordinary use, there is no preference between a T pad and a pi pad. These networks are interchangeable and the type of pad used is a matter of personal choice. Usually, the choice will depend upon the values of resistors that can be obtained easily.

Ganged Attenuator Pads. The input impedance of a symmetrical pad is equal to its output impedance. Thus the input of one pad can be used as the load resistance for a preceding pad. This can be kept up a great number of times and the total attenuation of the pads in tandem will be equal to the sum of the individual pad losses.

Thus, if we have three 50-ohm to 50-ohm pads (symmetrical), giving re-

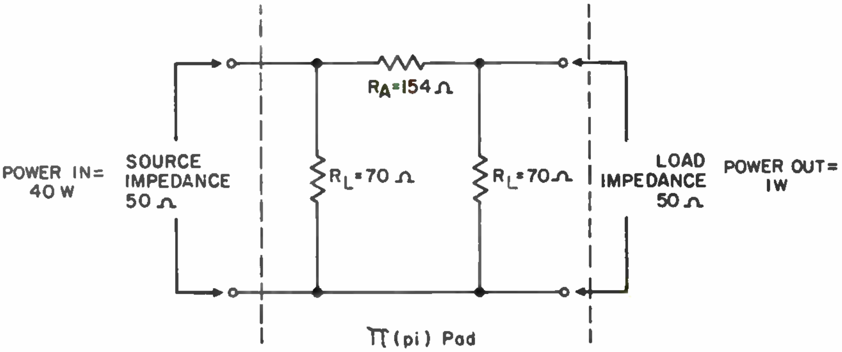


FIG. 10. Pi-pad attenuator (db = 16).

spectively 5, 8, and 4 db attenuation, we can connect these in any order and the whole combination will have an input impedance of 50 ohms. The attenuation will be 5 + 8 + 4 = 17 db when used with a 50-ohm load.

This is a very convenient feature of symmetrical pads, for it means that a great number of attenuation values can be realized with combinations of relatively few separate attenuators. Usually, if an attenuation of over 20 decibels is desired, it is better to obtain it by using two or more attenuators than by using one large-loss attenuator.

Balanced Attenuator Pads. All of the attenuator pads discussed so far have been designed for use with unbalanced lines which have one wire grounded. With balanced lines, where the wires are maintained at opposite potentials with respect to ground, these attenuators would not be suitable. The stray attenuator capacitance would upset the line balance and tend to increase noise pickup and cross talk.

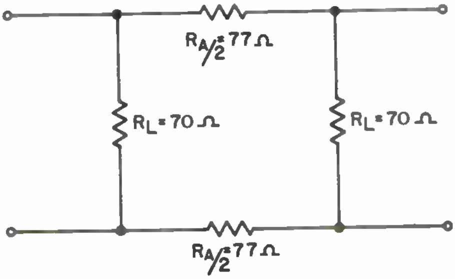


FIG. 11. Balanced pi pad—sometimes called an O pad.

The T and pi pads, however, can be balanced very easily. This is accomplished merely by splitting the series resistance arms in half, and inserting half of the resistance in the upper side of the line and the other half in the lower side of the line. Thus, the pi pad in Fig. 10 becomes the balanced pi pad shown in Fig. 11. In the same manner, the T pad of Fig. 8 is changed to the balanced version in Fig. 12. The balanced pi pad is sometimes called an O pad and the balanced T pad is sometimes called an H pad, because of their resemblance to these letters.

UNSYMMETRICAL PADS

In addition to being used to provide attenuation between equal impedances, T, H, pi, and O pads can also be used as attenuators between unequal impedances. When used in this way, they are designed to match the unequal impedances as well as provide attenuation. We have already studied one type of impedance-matching pad, which we called a minimum-loss L pad. However, the purpose of the L pad was to provide a minimum-loss matching network, and the attenuation it offered had to be considered because it was unavoidable, although undesirable.

The purpose of the networks which we will study now is not only to match unequal impedances but also to provide more attenuation than that which would be provided by a minimum-loss pad. When we studied the L pad, we said it was unsymmetrical because it did not look the same from both ends. The T and pi pads, which are used to match unequal impedances, also look different from each end and are called unsymmetrical T or pi pads.

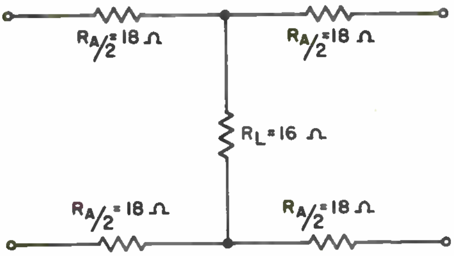


FIG. 12. Balanced T pad—sometimes called an H pad.

In studying the minimum-loss L-type matching pad, we learned that there will always be a certain amount of loss in a resistive matching pad. We also learned how to compute the amount of this minimum-loss in decibels and how to determine the proper resistance values. The minimum-loss L pad could also be considered as a modified T or π pad, as shown in Fig. 13A and B. Here we have shown the minimum-loss L pad as a T pad in which one of the arms has been reduced to zero. It can also be considered to be a pi pad in which one of the leg resistors has become so large it amounts to an open circuit, as shown in Fig. 13B.

From this, we can see that by introducing an extra arm or leg resistor of appropriate size, and changing the other resistance values, we can gain more attenuation and still maintain an impedance match. As soon as we do this, we will have changed our L-pad into an unsymmetrical T or pi pad. It should be noted that, although we can increase the attenuation above the minimum-loss and maintain an impedance match by using an unsymmetrical T or pi pad, we can never decrease the loss below the amount introduced by the minimum-loss L pad.

Therefore, one of the first things to do in designing an unsymmetrical attenuator is to determine the minimum possible loss. If this amount of attenuation is satisfactory, we will use an L pad as an attenuator. If we want more attenuation than the L pad will provide, we will design an unsymmetrical T or pi pad. However, if the minimum loss is more than we want, we will have to decide whether it is advisable to use an attenuator and an amplifier to match impedances or whether it is better to use some other method of matching impedances.

L-Pad Design. Before we go into the design of an unsymmetrical T or pi pad, there is one thing we should discuss regarding the minimum-loss L pad. When we considered the L pad earlier, we studied only left-handed pads like the one shown in Fig. 14A. In this circuit, the input impedance is larger than the output impedance and the arm resistor is in series with the input impedance. However, in a circuit like the one shown in Fig. 14B, the input impedance is smaller than the output impedance, and a right-handed L pad would have to be used.

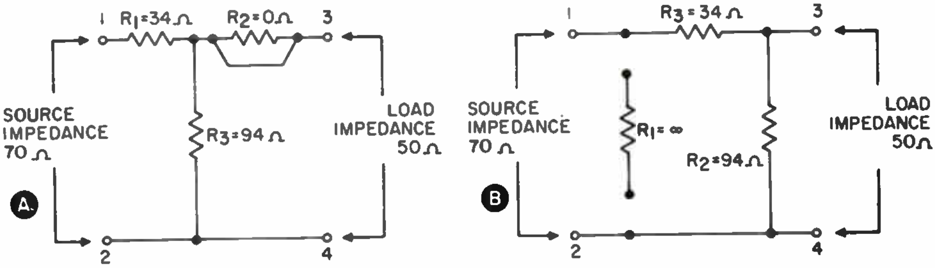


FIG. 13. The L pad can be considered as a modified T pad, as at A, or as a modified π pad, as at B.

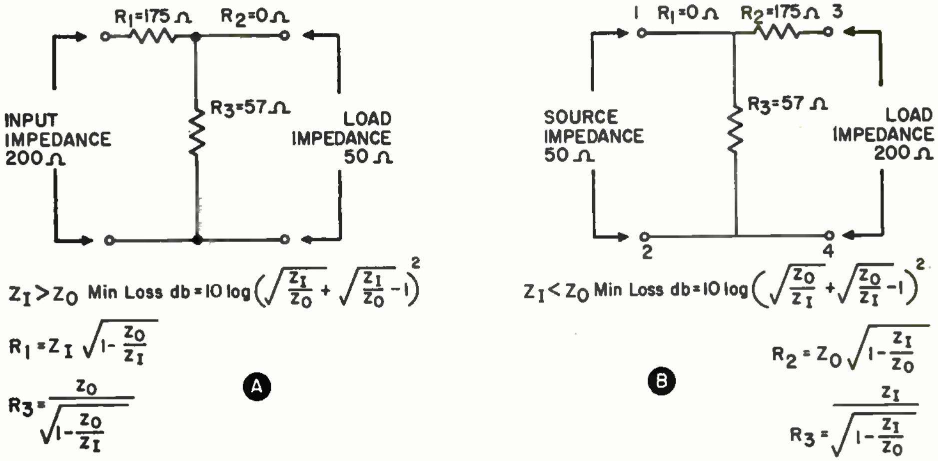


FIG. 14. Computing left-handed L pads, A; computing right-handed L pads, B.

The impedance values in the circuit shown in Fig. 14B are numerically the same, but reversed in position. The value of the arm resistor is the same as it was in a left-handed pad, but its position has changed. Because of this, our formulas for computing right-handed L pads are slightly different from those used in computing left-handed L pads. Also, the minimum loss in decibels will be figured a little differently. The formulas which we have already learned for computing left-handed L pads and their minimum loss are shown in Fig. 14A.

In a right-handed pad we compute for R2 and R3 instead of R1 and R3, and the formulas are slightly different. Now the positions of the output impedance and the input impedances in our formulas are just opposite what they were for the left-handed pads. You will also notice that the impedance relationships have been reversed in the minimum-loss formula.

Since computing the minimum loss is one of the first steps in designing any unsymmetrical attenuator network, this change in the minimum-loss formula is very important. As shown, when the input impedance, Z_I is greater than (>) the output impedance Z_O, the loss in decibels will be found from the following formula:

$$\text{Min. loss db} = 10 \log\left(\sqrt{\frac{Z_I}{Z_O}} + \sqrt{\frac{Z_I}{Z_O} - 1}\right)^2$$

However, when the input impedance Z_I is less than (<) the output impedance Z_O, the loss in decibels will be found from:

$$\text{Min. loss db} = 10 \log\left(\sqrt{\frac{Z_O}{Z_I}} + \sqrt{\frac{Z_O}{Z_I} - 1}\right)^2$$

Designing an unsymmetrical T or pi pad is simply using the proper formulas correctly. We will not attempt to show you how the formulas are derived, nor will you be expected to memorize them. The important thing is that you know how to use the formulas and where to find them when they are needed.

Unsymmetrical T or π Pads. The formulas for computing the resistance values of an unsymmetrical T pad are:

$$R_3 = \frac{2\sqrt{NZ_I\,Z_O}}{N - 1}$$

$$R_1 = Z_I\left(\frac{N + 1}{N - 1}\right) - R_3$$

$$R_2 = Z_O\left(\frac{N + 1}{N - 1}\right) - R_3$$

In the formulas, N is used to denote the power ratio: $P_I \div P_O$. We can find the value of N once we know our desired attenuation in decibels using the formula:

$$\text{db} = 10 \log \frac{P_I}{P_O}$$

Now let's use these formulas to compute an unsymmetrical T pad that will give us an attenuation of 15 db as shown in Fig. 15. The first thing we must do is determine whether or not an attenuation of 15 db with matched impedances is possible in this circuit. To do this, we compute the minimum possible loss for matched impedances. Since our input impedance is less than our output impedance, we use the formula:

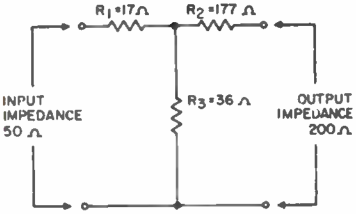


FIG. 15. Unsymmetrical T pad.

$$\text{Min. loss db} = 10 \log \left(\sqrt{\frac{Z_O}{Z_I}} + \sqrt{\frac{Z_O}{Z_I} - 1}\right)^2$$

$$= 10 \log \left(\sqrt{\frac{200}{50}} + \sqrt{\frac{200}{50} - 1}\right)^2$$

$$= 10 \log (\sqrt{4} + \sqrt{4 - 1})^2$$

$$= 10 \log (2 + \sqrt{3})^2$$

$$= 10 \log (2 + 1.73)^2$$

$$= 10 \log 3.73^2$$

$$= 10 \log 13.9$$

$$= 11.43 \text{ db}$$

Since our desired attenuation of 15 db is more than this minimum of 11.43 db, we know that it is possible to construct the desired attenuator.

Now, we must find the correct value of N to use. By substituting N in place of the power ratio in our formula:

$\text{db} = 10 \log \frac{P_I}{P_O}$ we get:

$$\text{db} = 10 \log N$$

$$15 = 10 \log N$$

$$\frac{15}{10} = \log N$$

$$1.5 = \log N$$

Checking our log tables, we find that 1.5 is the logarithm of 31.7, which we can round off to 32.

Now, using our formula for the leg resistor R_3, we find:

$$R_3 = \frac{2\sqrt{NZ_I Z_O}}{N - 1}$$

$$= \frac{2\sqrt{32 \times 50 \times 200}}{32 - 1}$$

$$= \frac{2\sqrt{32 \times 10{,}000}}{31}$$

$$= \frac{2 \times 100 \sqrt{32}}{31}$$

$$= \frac{200 \times 5.65}{31}$$

$$= \frac{1130}{31}$$

$$= 36\ \Omega$$

Next, our arm resistor R_1 is:

$$R_1 = Z_I \left(\frac{N + 1}{N - 1}\right) - R_3$$

$$= 50 \left(\frac{32 + 1}{32 - 1}\right) - 36$$

$$= \frac{1650}{31} - 36$$

$$= 53 - 36$$

$$= 17\ \Omega$$

And our other arm R_2 is:

$$R_2 = Z_O\left(\frac{N+1}{N-1}\right) - R_3$$

$$= 200\left(\frac{32+1}{32-1}\right) - 36$$

$$= 200 \times \frac{33}{31} - 36$$

$$= \frac{6600}{31} - 36$$

$$= 213 - 36 = 177\ \Omega$$

If we prefer, we can use a pi pad as shown in Fig. 16. The following formulas are for computing unsymmetrical pi pads.

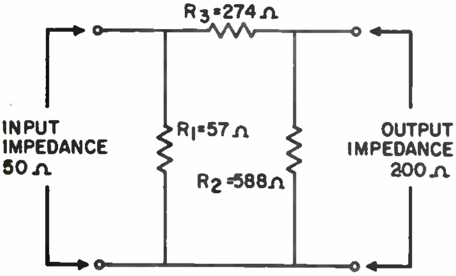


FIG. 16. Unsymmetrical pi pad.

The arm R_3 is:

$$R_3 = \frac{N-1}{2}\sqrt{\frac{Z_I\, Z_O}{N}}$$

$$= \frac{32-1}{2}\sqrt{\frac{50 \times 200}{32}}$$

$$= \frac{31}{2}\sqrt{\frac{10{,}000}{32}}$$

$$= \frac{31}{2} \times 100\sqrt{\frac{1}{32}}$$

$$= \frac{3100}{2} \times \frac{1}{5.65}$$

$$= \frac{3100}{11.3} = 274\ \Omega$$

The leg R_1 is:

$$\frac{1}{R_1} = \frac{1}{Z_I}\left(\frac{N+1}{N-1}\right) - \frac{1}{R_3}$$

$$= \frac{1}{50}\left(\frac{32+1}{32-1}\right) - \frac{1}{274}$$

$$= \frac{1}{50} \times \frac{33}{31} - \frac{1}{274}$$

$$= \frac{33}{1550} - \frac{1}{274}$$

$$= .0213 - .0036 = 0177$$

If $\frac{1}{R_1} = .0177$, then $R_1 = \frac{1}{.0177}$

$$= 57\ \Omega$$

The leg R_2 is:

$$\frac{1}{R_2} = \frac{1}{Z_O}\left(\frac{N+1}{N-1}\right) - \frac{1}{R_3}$$

$$= \frac{1}{200} \times \frac{33}{31} - \frac{1}{274}$$

$$= \frac{33}{6200} - \frac{1}{274}$$

$$= .0053 - .0036$$

$$= .0017$$

If $\frac{1}{R_2} = .0017$, then $R_2 = \frac{1}{.0017}$

$$= 588\ \Omega$$

Thus, we can construct either a T or a pi pad that will match unequal impedances and give us 15 db attenuation. A balanced T (H) pad or a balanced pi (O) pad could be constructed by splitting the arm resistors and dividing them between the upper and lower lines.

VARIABLE ATTENUATORS

The attenuation introduced by an L pad, a T pad, or a pi pad can be made

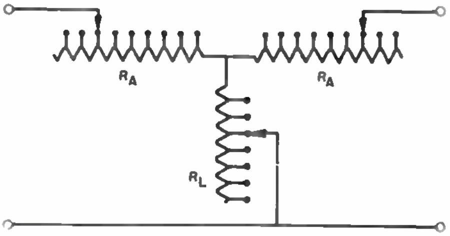


FIG. 17. The usual style of tapped T-pad variable attenuator.

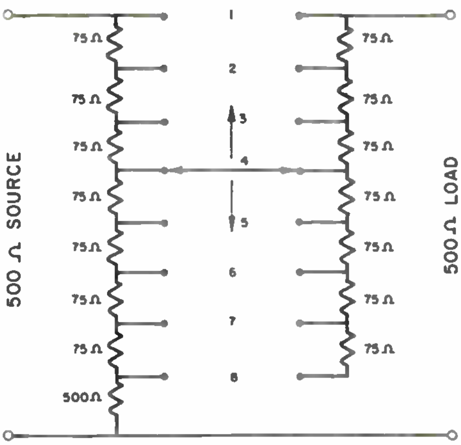


FIG. 18. An approximate T pad using only two variable resistors.

adjustable by using variable resistors for the arms and legs. The T pad of Fig. 8, for example, could be made with variable R_A and R_L values.

If this is done, however, the relations outlined in the table of Fig. 9 must be maintained or the variable pad will not have constant input and output impedances. We could do this by using taper-wound variable resistances ganged together so that all resistances varied by the proper amount when one control was operated. However, this would be quite difficult to achieve in actual practice because each resistor would have to be calibrated and wound with such precision that it would become quite costly.

A reasonable, practical design of the variable attenuator is made possible by the fact that attenuation does not need to be continuously variable. If the variations are made in equal steps of less than 2 db each, the variation will appear to be continuous for most purposes. This allows us to use a set of fixed resistors and a three-gang switch as shown in Fig. 17.

One advantage of using step attenuation in the design of the variable T pad is that such an arrangement can be calibrated very accurately. In addition, the gang switch can be made with large wiping contacts which will keep contact noise at a minimum. This is in contrast to a rheostat or a potentiometer which seldom can be reset to a given point, and usually has a high degree of contact noise.

To increase the amount of attenuation in this pad, the values of R_A must be increased and the value of R_L must be decreased. For this reason, then, it is possible to combine one of the R_A's with R_L so that the simpler construction shown in Fig. 18 can be used.

In the figure, the right-hand resistance forms the right arm of the T pad, the upper part of the left-hand resistance forms the left arm, and the lower part forms the leg. This arrangement is not a true T pad, but only an approximation since it is not possible to make the attenuator have exactly constant values of input and output resistance at all settings.

As shown in the table of Fig. 19, it varies from 336 to 861 ohms.

It will be noted that the use of this particular attenuator involves a loss of 1.9 db at the minimum setting. This is called the insertion loss of this particular device.

Decade Attenuator Pads. Suppose we have need for an attenuator adjustable in one decibel steps from 0 to

Switch position	Input Resistance	db Loss
1	336	1.9
2	432	3.5
3	522	5.0
4	605	6.5
5	680	7.9
6	748	9.3
7	808	10.8
8	861	12.4

FIG. 19. Input resistance and db loss of the approximate T pad for each switch point.

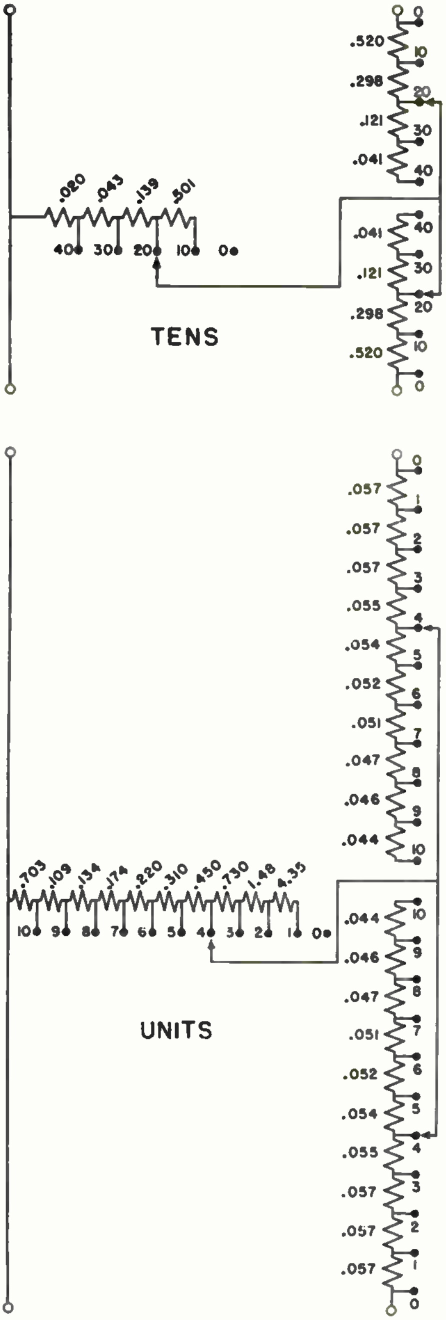


FIG. 20. A decade attenuator adjustable in 1 db steps from 0 to 50 db, designed for a source-load impedance of 1 ohm.

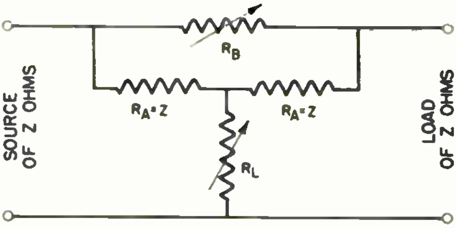


FIG. 21. The bridged-T is a true symmetrical pad with only two variable resistors.

50 that maintains perfect impedance matching at all settings. We could, of course, design a conventional T pad having 50 steps, but this would be expensive and awkward to use.

A better method would be to build two attenuators, one having four steps of 10 decibels each, and the other having ten steps of 1 decibel each. Then, if these are constant-impedance pads, they can be connected in tandem so that the separate attenuations will add. Thus, one knob controls the tens, and the other controls the units of attenuation. Such an arrangement is called a decade attenuator.

The design for such a decade attenuator is shown in Fig. 20. This decade pad is designed to work between a source of 1 ohm and a load of 1 ohm. To find the values for any other source and load impedance, simply multiply the value shown alongside each resistor by the impedance Z.

The Bridged T. A modification of the T pad, of considerable importance because it requires only two variable resistors, is shown in Fig. 21. This is known as the bridged T. It is a symmetrical attenuator having two fixed arms, bridged from input to output by a variable arm, and a variable leg.

The resistances of the fixed arms R_A are always equal to the input-output impedance Z. The bridge and leg resistors R_B and R_L are related to the impedance Z in this way:

$$R_B = B \times Z \text{ and}$$

$$R_L = L \times Z.$$

The multiplying factors, B and L, can be determined from the table in Fig. 22. Pay particular attention to the arm and leg factors for 6-db attenuation. Both are almost exactly equal to 1. This means that 6 db of attenuation can be obtained at any impedance by connecting four resistors, all equal to the impedance, in a bridged T. Any other degree of attenuation can be obtained by changing R_B and R_L to the proper values.

Attenuation db	Bridge-arm factor B	Leg factor L
0	0	∞
1	0.122	8.20
2	.259	3.86
3	.413	2.42
4	.585	1.71
5	.778	1.285
6	.995	1.005
7	1.239	0.808
8	1.512	.661
9	1.818	.550
10	2.162	.462
20	9.000	.111
30	30.62	.0326
40	99.00	.0101

FIG. 22. Multiplying factors for design of the bridged-T.

You have seen how networks can be designed to give impedance-matching with minimum attenuation, or to give a desired amount of attenuation. Now let's look at some networks designed to correct uneven attenuation or phase shift at different frequencies. These are called "equalizers."

Equalizers

Transmission lines and certain types of equipment ordinarily introduce a certain amount of distortion in a signal because of unequal attenuation and phase shift at the various frequencies. It would be extremely difficult to design lines and equipment that would always provide a distortion-free signal. The more practical solution is to use compensating networks to introduce additional attenuation or phase shift so that all frequencies will be affected in substantially the same manner.

LINE EQUALIZERS

Long lines (such as telephone lines or cables) ordinarily attenuate high frequencies more than the low frequencies. Capacitance between the wires acts like a capacitor connected across the line ahead of the load, shorting out the high frequencies. A crude form of compensation could be obtained by connecting a capacitor in series with the line to partially block the low frequencies while passing the highs. A more practical arrangement uses an inductance-resistance combination shunted across the line to cause an equivalent loss of the low frequencies and balance the response.

Such an arrangement is the Western Electric 23A Equalizer shown in Fig. 23. As you can see, it consists of a coil and a capacitor in parallel, and a tapped series resistance. The components are mounted in an aluminum-finished metal box, and the resistor taps are brought out to terminals at one end of the box, so any needed value of resistance can be selected.

It can be easily adjusted to an unloaded line with ordinary station equipment. Suppose it is to be adjusted to a circuit consisting of the sending-station line amplifier, repeating coil, (which is an impedance-transforming device similar to a transformer), transmission line, receiving-station repeating coil, and receiving-

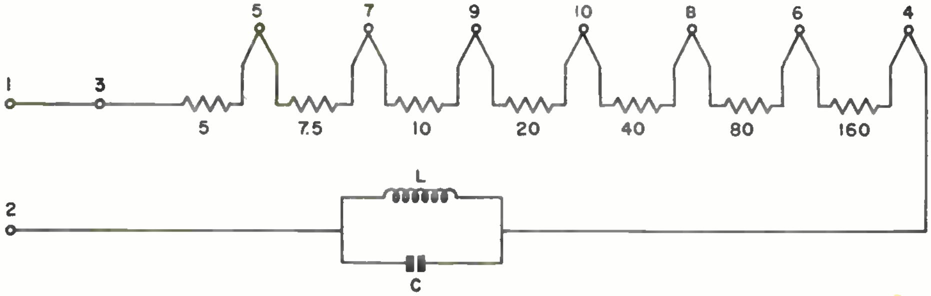


FIG. 23. The Western Electric 23A equalizer.

station line amplifier as shown in Fig. 24.

VU meters are connected across the line following the sending and receiving line amplifiers, and the receiving amplifier is terminated in a 600-ohm load. An attenuator pad is used ahead of the repeating coil at the sending end to prevent cross-talk or interference with other lines in the same cable. Another attenuator is used at the receiving end to avoid overloading the amplifier. To see what values of resistance to use in the equalizer, the output of a variable-frequency oscillator is fed into the sending amplifier, and the loss at 1000 cycles and 8000 cycles noted.

Then the equalizer is connected across the line side of the receiving repeating coil, but an adjustable resistance box is connected in place of the tapped resistor in the equalizer. That is, terminal 2 of the equalizer is connected to one side of the line. The resistance box is connected between terminal 4 of the equalizer and the other side of the line. Terminal 1 of the equalizer is left open. Various resistance values are tried (using the resistance box) until the loss is approximately the same at 1000 and 8000 cycles. Then the resistance box is removed and the portion of the fixed resistance in the equalizer with a value closest to that determined by experiment is connected in its place. This is done by connecting terminal 1 to the line from which the resistance box was removed, and moving the lead from the L-C combination from terminal 4 to the proper terminal. For example, if 12 or 13 ohms is needed, the lead would be moved from terminal 4 to terminal 7, since the resistance from terminal 7 to terminal 1 is 12.5 ohms, which is as close as we can get.

For temporary lines or intermittent service where a permanent installation is not justified, an adjustable equalizer such as the Western Electric 279A equalizer panel shown in Fig. 25 can be used to connect it to any one of several lines as the occasion requires.

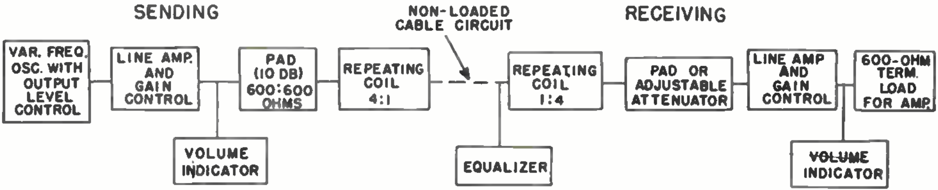


FIG. 24. Setup for equalizing a line.

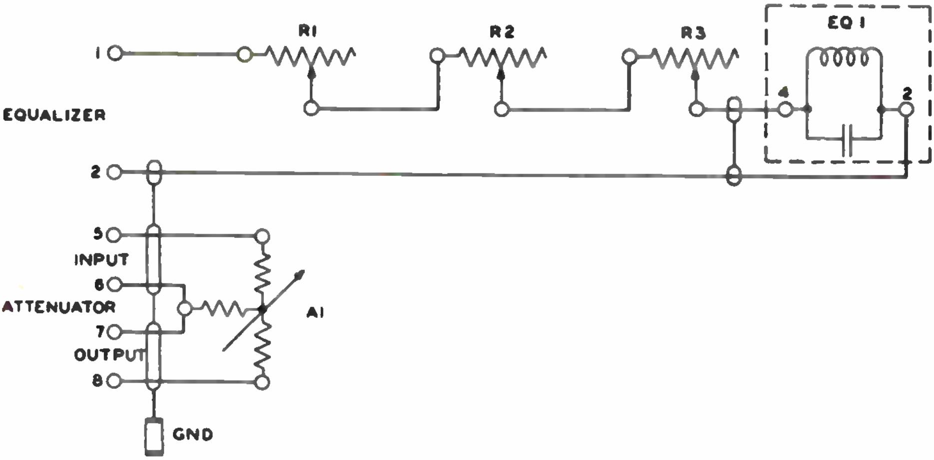


FIG. 25. The Western Electric 279A equalizer panel.

PICKUP EQUALIZERS

Another way in which equalizers are used is to compensate for the electrodynamic characteristics of phonograph and tape pickups. They are also used to compensate for the particular recording curve used in making records. These are called pickup equalizers.

Recording methods may be divided into two general classes: constant-velocity and constant-amplitude. When a record is cut, the stylus in the cutting head cuts a groove in the record. When no signal is applied, the groove forms a perfect spiral. When a signal is applied, the stylus moves in a transverse (side to side) direction, making a slight wiggle in the groove.

When a signal of constant amplitude is applied to a constant-velocity cutting head, the transverse velocity of the stylus is constant regardless of frequency, but the displacement from side to side decreases with frequency. With a constant-amplitude cutting head, the transverse displacement of the stylus is constant (for tones of constant amplitude), but the transverse velocity of the stylus varies directly with the frequency.

Just as cutting heads can be divided into two types, record pickup heads may also be divided into two classes, "velocity-operated" and "amplitude-operated." In a velocity-operated pickup, the output signal is generated by changing the flux of a permanent magnet as it passes through a coil. Different types of heads (magnetic, dynamic, variable reluctance) accomplish this in slightly different ways, but the operating principle is the same.

The voltage generated is proportional to the rate at which the flux changes, and the flux is changed by the movement of the stylus. Thus, the signal voltage generated is dependent on the speed of the stylus. This pickup is the natural opposite of a constant-velocity recorder. If a constant-level signal is recorded, a constant-level output is obtained.

The output of an amplitude-operated pickup is constant for constant groove undulation (side to side displacement) amplitude. Common amplitude-operated pickups are the crystal and ceramic types. These operate on the piezo-electric effect, generating a voltage by the physical distortion of a crystal. A constant-amplitude signal recorded with a crystal cutter will be

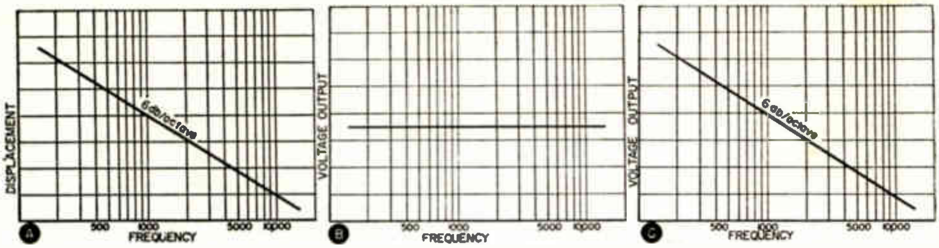


FIG. 26. A, variations of magnetic-cutter stylus displacement with frequency. B, output voltage of magnetic pickup on constant-velocity recording. C, output voltage of crystal pickup on constant velocity recording.

reproduced as a constant output voltage when played back through a crystal pickup. A constant-amplitude signal recorded with a constant-velocity cutter will be reproduced as a voltage which falls off at the rate of 6 db per octave as the frequency is increased.

Fig. 26A shows how the undulation amplitude varies with frequency in a constant-velocity record for tones of equal signal level. When a magnetic play-back head is used, the amplitude of the output signal is the same at all frequencies as shown in Fig. 26B, but with an amplitude-operated pickup, the voltage falls off as in Fig. 26C.

Fig. 27A shows the variation in stylus displacement with frequency for tones of equal amplitude when recorded with a constant-amplitude recording head. If the record is played back through a constant-amplitude pickup, the output voltage is the same at all frequencies as shown in Fig. 27B. If played back through a constant-velocity pickup, the output is as shown in Fig. 27C.

Recording Curves. In actual practice, both constant-velocity and constant-amplitude characteristics are used on parts of any record. When attempts were made to extend the high-frequency range of recordings, difficulty was experienced in keeping the high-frequency notes from dropping down to the noise level. Also, with constant-velocity recording, the stylus sometimes cut into the next groove when a loud, low note was recorded. These problems were solved by pre-emphasizing the highs and de-emphasizing the lows during recording, and using equalizers in the play-back amplifiers to make the necessary compensation.

The only trouble with this arrangement was that there was no agreement between companies as to exactly what system to use, that is, how much pre-emphasis was necessary or at what

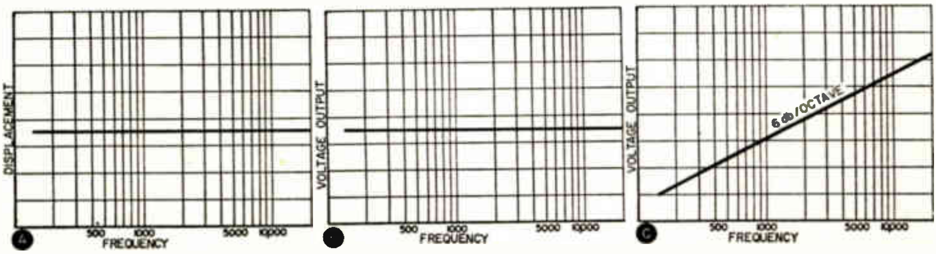


FIG. 27. A, crystal cutter stylus displacement variation with frequency for constant signal level. B, voltage output variation when record (in A) is played back through crystal pickup. C, output voltage variation when same record is played through magnetic pickup.

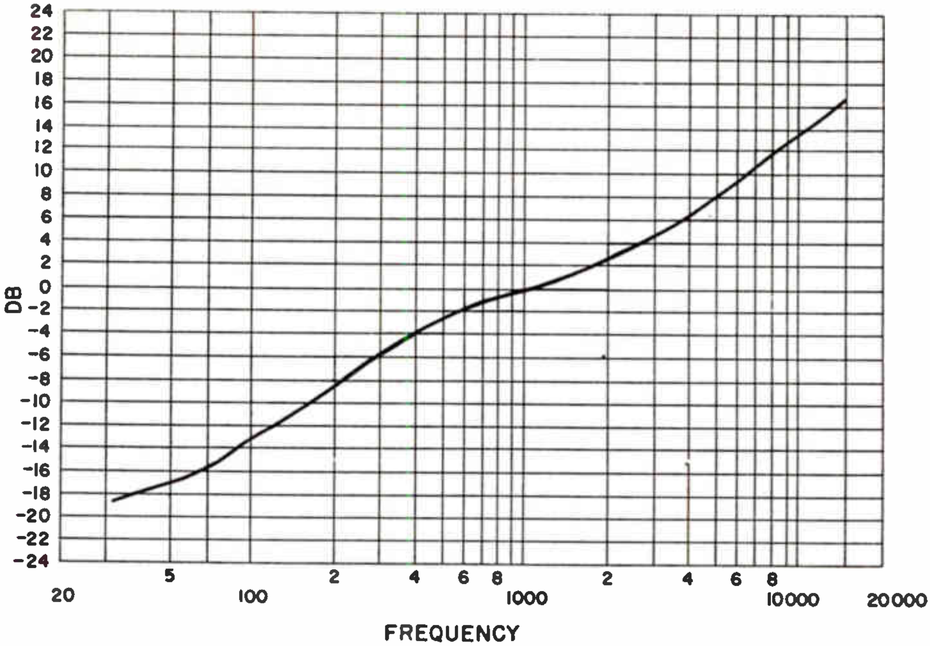


FIG. 28. The RIAA recording curve.

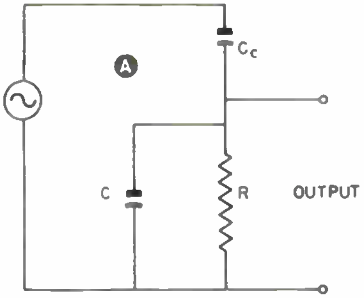
frequency it should start, etc. Various techniques were tried, and several recording curves were developed. As a result, it was very difficult to design playback amplifiers to reproduce all records satisfactorily with any type of pickup. Recently, the Recording Industries Association of America adopted a standard curve and recommended it to the entire recording industry. The RIAA curve, shown in Fig. 28, is identical to the NARTB (National Association of Radio and Television Broadcasters) curve and also to RCA's Orthophonic curve. The Audio Engineering Society has recommended it as a replacement for their AES curve. Nearly all the major record manufacturers now use this curve on their new records.

Equalizer Circuits. For best possible frequency response, a pickup must be terminated correctly at the input of the amplifier. The ideal pickup and termination would give a flat frequency response over the entire audio range.

Fig. 29 shows the equivalent circuit of a ceramic cartridge and its termination. The pickup can be thought of as a generator and a capacitor in series, and the load as a resistance and a capacitor in parallel. When the two are connected, an RC voltage divider results. At low frequencies, the reactance of C is so high it can be ignored, as in Fig. 29B, but its effects increase as the frequency goes up, as shown in Fig. 29C.

For any given pickup, C is fixed, as it depends on the cable length and the amplifier construction, so R is the only part that can be varied. Fig. 29D shows how varying R affects the output.

The equivalent circuit of a magnetic pickup and its termination is shown in Fig. 30A. This circuit contains inductance, capacitance, and reactance and acts as a damped resonant circuit. If R_L is too large, the output will have resonant peaks at frequencies deter-



EXACT EQUIVALENT LOW FREQUENCY HIGH FREQUENCY

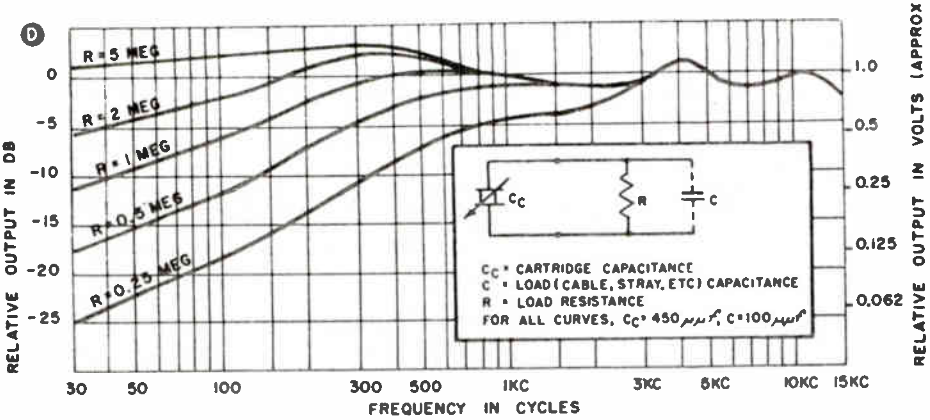


FIG. 29. A, B, C equivalent circuits of ceramic cartridge and termination; D, change in output with change in terminating resistance.

mined by the values of L and C_S. If R_L is small, C_S is effectively shorted and the inductance will cause the highs to fall off. Using a longer cable would cause C_S to increase, and there would be resonant peaks at a lower frequency. If R_L is reduced to compensate for this, the high-frequency output is reduced. The best frequency range is obtained by keeping the cable capacitance small and R_L high.

Fig. 30B shows a crystal pickup and its termination. The output of a crystal cartridge falls off rapidly at high frequencies. R_1 and C in series with R_2 correct for this. At low frequencies, capacitor C has little effect on the signal appearing at the output.

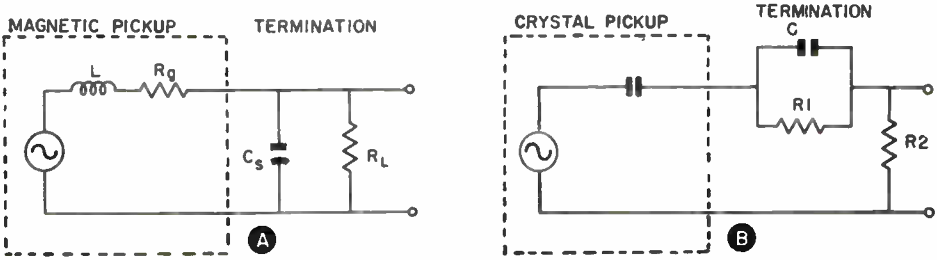


FIG. 30. Equivalent circuit and input termination for A, magnetic, and B, crystal pickup.

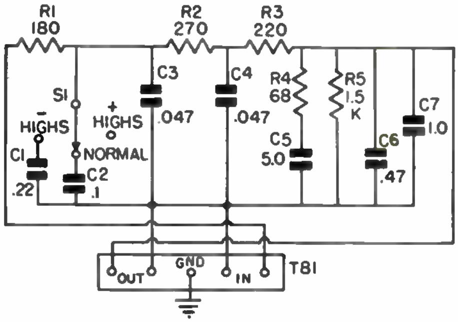


FIG. 31. The RCA MI-11888 pickup equalizer.

As the frequency goes up, the reactance of C goes down. This reduced reactance shunting resistor R_1 increases the signal at the output.

Turntable Equalizers. A typical equalizer for use with a broadcast turntable is shown in Fig. 31. This is the RCA MI-11888, designed to work with the RCA Type 70 Series turntable and the BQ-2A turntable, and is for use only with the MI-11874-4 pickup head.

The equalizer is mounted inside the turntable cabinet in the right-hand front corner, where it will be convenient for use by the operator.

Three settings of the equalizer are provided. In the diagram, the switch is shown in the "normal" position. When it is desired to accentuate the highs, the switch is moved to the "+Highs" position, which removes some of the shunt capacitance from the circuit. When the opposite effect is desired, the switch is thrown to the "—Highs" position, which adds shunt capacitance to the circuit.

The response curves for the different settings of the equalizer switch are shown in Fig. 32.

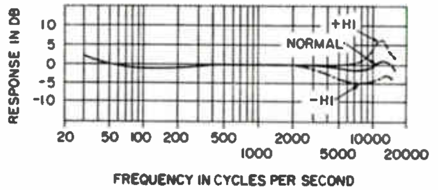


FIG. 32. Frequency response curves for the MI-11888.

TAPE SYSTEM EQUALIZERS

There are a number of factors that influence the frequency response of a record and play-back tape system. Fig. 33 shows the response curves for two standard tape speeds—15 inches per second and 7.5 inches per second. The slower-moving tape has the poorer high-frequency response. This is because, when a signal is recorded on a magnetic tape, the particles of the coating form many very small areas which act like tiny magnets having north and south poles. The slower the tape moves past the recording head or the higher the frequency of the applied signal, the shorter the magnetic bars become. This causes a canceling effect between the opposite poles, which reduces the magnetism induced in the tape.

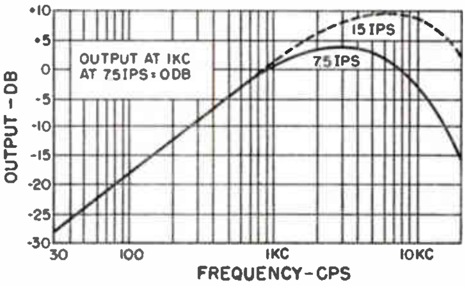


FIG. 33. Response of a record playback head.

Another cause of high-frequency loss is that the recording head is largely inductive. Thus, it has more impedance at high frequencies, decreasing the strength of the magnetic field between the pole pieces.

When the tape is played back, the voltage induced in the play-back coil varies with the rate of change of the flux lines. A high-frequency tone of the same amplitude occupies a shorter length of tape than a lower-frequency tone of the same amplitude. Thus, the

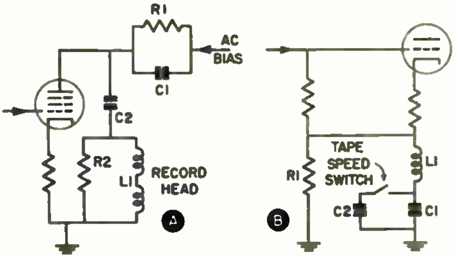


FIG. 34. Circuits for pre-emphasis.

change of flux lines is at a faster rate at higher frequencies (or a faster speed) than at a low frequency (or a slower speed).

To get a linear frequency response in a tape-recorder system, equalizing networks are necessary to boost the amplitude of the frequencies at both the high and low ends of the audio range. The usual practice is to boost the highs in the recorder and the lows (and sometimes also the highs) in the play-back amplifier. The former is called pre-emphasis and the latter, post-emphasis.

Pre-Emphasis. Two typical pre-emphasis circuits are shown in Fig. 34. In Fig. 34A, capacitor C_2 is in series with the recording head across the output of the amplifier tube. The reactance of C_2 decreases as the frequency increases, so a high-frequency signal will produce a higher current flow in the coil of the recording head than a low-frequency one will.

In Fig. 34B, a series-resonant circuit in the amplifier cathode circuit is used, At low frequencies, a degenerative voltage is developed across resistor R_1, feeding an out-of-phase signal to the grid, decreasing the gain. At higher frequencies, coil L_1 and capacitor C_1 (or C_1 and C_2 in parallel) have an increasing shunting effect on resistor R_1, decreasing the feedback, and the gain goes up. Capacitors C_1 and C_2 are connected in parallel for high tape speeds, but the switch is opened at low speed.

Post-Emphasis. Two typical post-emphasis circuits are shown in Fig. 35. In Fig. 35A, the bass response is boosted by the series network consisting of capacitor C_2 and resistors R_2 and R_3. The reactance of C_2 is so high at low frequencies that the series network of C_2 and R_2 has no shunting effect, and the lows pass unattenuated to the grid of the next stage. As the frequency goes up, the shunting effect of the two components increases, and a lower proportion of the high-frequency signal appears at the grid. Capacitor C_3 is an adjustable treble control used to correct for the very-high-frequency losses in a tape recorder system. At the higher frequencies, C_3 shunts some of the highs around R_3 and on to the grid.

In the circuit shown in Fig. 35B, the middle range of frequencies is fed back to the input circuit through re-

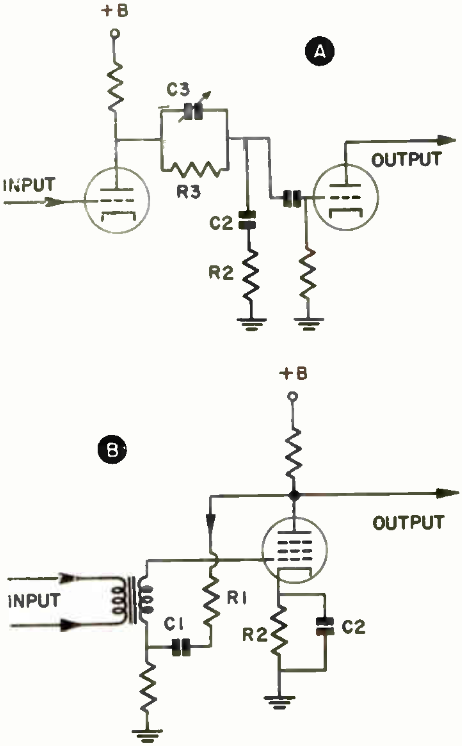


FIG. 35. Post-emphasis circuits.

sistor R_1 and capacitor C_1. There is no feedback of lows because of the rising capacitance of capacitor C_1. The feedback reduces the gain so the gain decreases with an increase in frequency.

The values of resistor R_2 and capacitor C_2 can be chosen to give a small amount of boost at very high frequencies. If C_2 is small, its low reactance at very high frequencies prevents cathode feedback and increases the high-frequency gain.

These are only some of the many uses for equalizers in broadcast service. Equalizers and filters, which we will take up in the next section of this text, are used to extend the frequency range of a sound system, to add sound effects without the use of mechanical apparatus, to remove undesirable sound effects, to improve tonal qualities resulting from poor acoustical location, and to compensate for variations in system response, acoustical conditions, and program material.

Filters

Basically, filters consist of an arrangement of reactive components that will respond in certain predetermined ways to different frequencies. Filters can be designed to pass low-frequency signals and block signals at high frequencies. Others can be designed to pass high frequencies and block low frequencies. Still others may either pass or block certain definite bands of frequencies. A fundamental rule is that a network cannot act like a filter unless it contains some reactive component, such as a coil or capacitor, that changes its reactance with frequency.

BASIC FILTER CIRCUITS

The operation of the filter depends not only upon the components used, but also on the values and circuit arrangements of the parts. Filter elements can be connected in series with the load or in parallel with the load. Let us see what effect these connections have.

High-Pass Filter. A capacitor in series with the load, or a coil in parallel with the load, as shown in Fig. 36A, forms a simple high-pass filter. At low frequencies, the current is blocked from the load by the capacitor or shorted around the load by the coil. As the frequency increases, more and more current is passed by the capacitor and reaches the load, or if a coil is used, the coil reactance goes up as

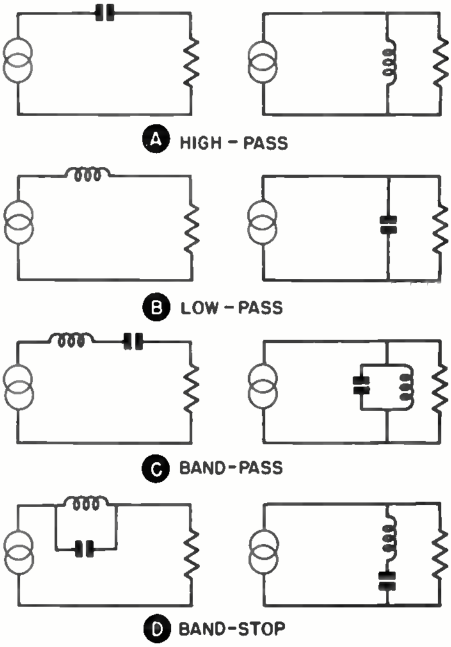


FIG. 36. Types of filters.

the frequency increases and more of the current is forced through the load.

Low-Pass Filter. If we put the capacitor in parallel with the load or the coil in series with the load as at B, the effect will be reversed, and we will have a low-pass filter.

Band-Pass Filter. Suppose we use both a coil and a capacitor as in Fig. 36C. If we put them in series with the load and each other we will have a band-pass circuit. Now, low frequencies will be blocked by the capacitor, and the higher frequencies will be blocked by the coil. However, at some intermediate frequency, the inductive and capacitive reactance will be exactly equal and opposite, the circuit will be series resonant and will pass current. This is a band-pass filter because a small band of frequencies about the resonant point will be passed. If we put the two in parallel with the load, low frequencies will be bypassed around the load by the coil, and high frequencies by the capacitor. At some frequency the two will be resonant, and act like a high impedance and the current will flow through the load.

Band-Stop Filter. Band-stop filters are shown in Fig. 36D. When the coil and capacitor are connected in parallel with each other and placed in series with the load, current reaches the load through the capacitor at high frequencies and through the coil at low frequencies. At resonance, the blocking action of the circulating current in the resonant circuit prevents current from reaching the load. If they are connected in series with each other across the load, at resonance the current will be shorted around the load. Above and below resonance, either the coil or the capacitor will block the current and force it through the load.

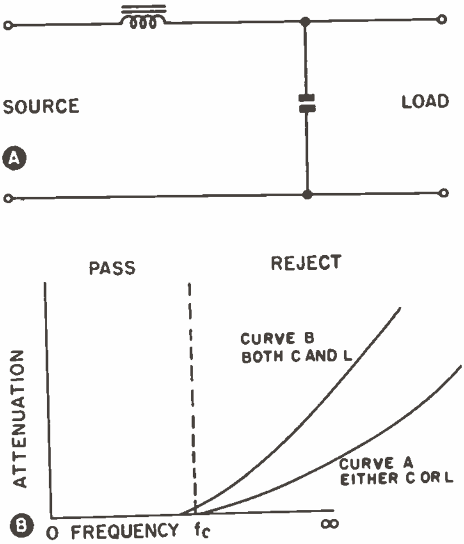


FIG. 37. Basic low-pass L filter, A; filter response curves, B.

These four basic circuits (low-pass, high-pass, band-pass, band-stop) illustrate the principles of filtering, but, in actual practice, we have to consider the sharpness of the cut-off action and the effect of the filter on the impedance relationship. For this rea-

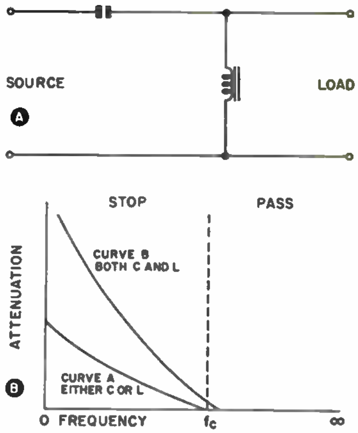


FIG. 38. Basic high-pass L filter, A; filter response curves, B.

son, most practical filter circuits are combinations of the principles we have discussed. One of the simplest of these is the L filter.

L Filter. Let's see why the circuit in Fig. 37 gives an improved response. Either the coil or capacitor alone forms a low-pass filter. With either one alone, the current in the load will decrease as the frequency goes up until, finally, at some high frequency practically no current reaches the load. By using both components, we get the benefit of two effects. If the values are chosen properly, at the cut-off frequency the coil will begin to block quite a lot of current and the capacitor will begin to pass a substantial amount of current. Thus, the coil blocks some of the current and the capacitor passes some that gets through the coil, and we have a sharper response curve as shown by curve B in Fig. 37B.

The high-pass filter shown in Fig. 38 also combines capacitance and inductance in an L-type filter arrangement. Notice that in the circuit in Fig. 38A, we use a series capacitor and a shunt coil to provide a sharper attenuation than we would get by using either component by itself. The response curves are shown in Fig. 38B.

Band-pass and band-stop filters can also be improved by arranging the components in an L network. In Fig. 39 we show the network and the curves for a band-pass filter. If the series-resonant and the parallel-resonant circuit shown in Fig. 39A are designed to resonate at the same frequency, the cut-off will be quite sharp as shown by the curves in Fig. 39B. This will result in a highly discriminating filter and a very narrow band of frequencies will be allowed to pass.

However, if we make the two circuits resonate at slightly different frequencies, we can broaden the pass-band as shown by the curves in Fig. 39C. Here, all the frequencies between the resonant frequency of the series circuit, denoted by f_1, and the resonant frequency of the parallel circuit, de-

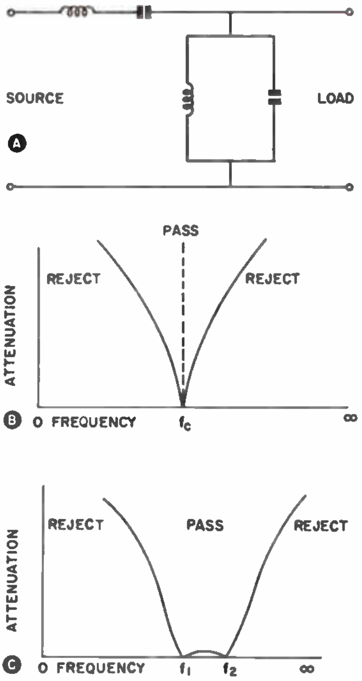


FIG. 39. L-type band-pass filter, A; sharp cut-off, narrow-band with arm and leg resonating at same frequency, B; sharp cut-off, wide-band with arm and leg resonating at different frequencies, C.

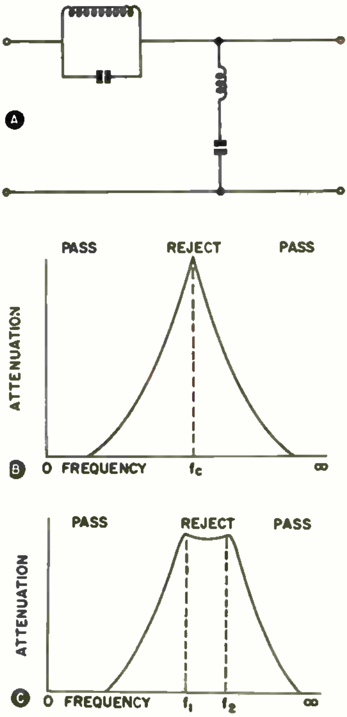


FIG. 40. L-type band-stop filter, A; sharp cut-off narrow band with arm and leg resonating at same frequency, B; sharp cut-off, wide band with arm and leg resonating at different frequencies, C.

noted by f_2, will be passed while all others will be rejected.

Similarly, a band-stop filter can be made by using the L networks shown in Fig. 40A. Notice that now the parallel resonant circuit is in series with the load and the series resonant circuit is in parallel with the load. When the parallel circuit resonates, it will tend to block current to the load. When the series circuit resonates, it will tend to short any signals away from the load. If the two circuits are designed to resonate at the same frequency, a narrow band of frequencies will be stopped as shown by Fig. 40B. If there is a difference in their resonant frequencies, the stop band will become wider as shown in Fig. 40C.

Although L pads can be designed to give sharp cut-off characteristics and provide almost any type of filtering action, they are unsymmetrical. In many filtering applications, it is very important to have the impedance matching in both directions. In such cases symmetrical filters must be used.

The low-pass L section shown in Fig. 37A can be made into a symmetrical *T section* by splitting the inductance L in two, and placing one half on each side of the shunt capacitor C. The same L section can be changed into a symmetrical *pi section* by using two capacitors of half the former capacity, and locating one at each end of the inductance.

In a similar manner, the band-pass and band-elimination L sections can also be made into symmetrical T or pi sections. A summary of the more common filter section forms, together with their attenuation characteristics, is given in Fig. 41.

MULTI-SECTION FILTERS

Now that we know that symmetrical filter sections "repeat" the load resistance for their input impedance, it is obvious that we can operate several filter sections in tandem. Thus, if we have three low-pass T sections, each designed for an impedance, let us say of 500 ohms, we can arrange them as shown in Fig. 42A. Here the second section acts as the load impedance for the first, and the input impedance of the last section is the load for the second filter section.

We may continue this arrangement for almost any number of sections. In all cases, however, the generator still works into a 500-ohm input impedance, and the impedance at the output continues to match the 500-ohm load.

Since the individual attenuations add, the tandem arrangement will attenuate the unwanted frequencies roughly three times as much as an individual section, while the wanted fre-

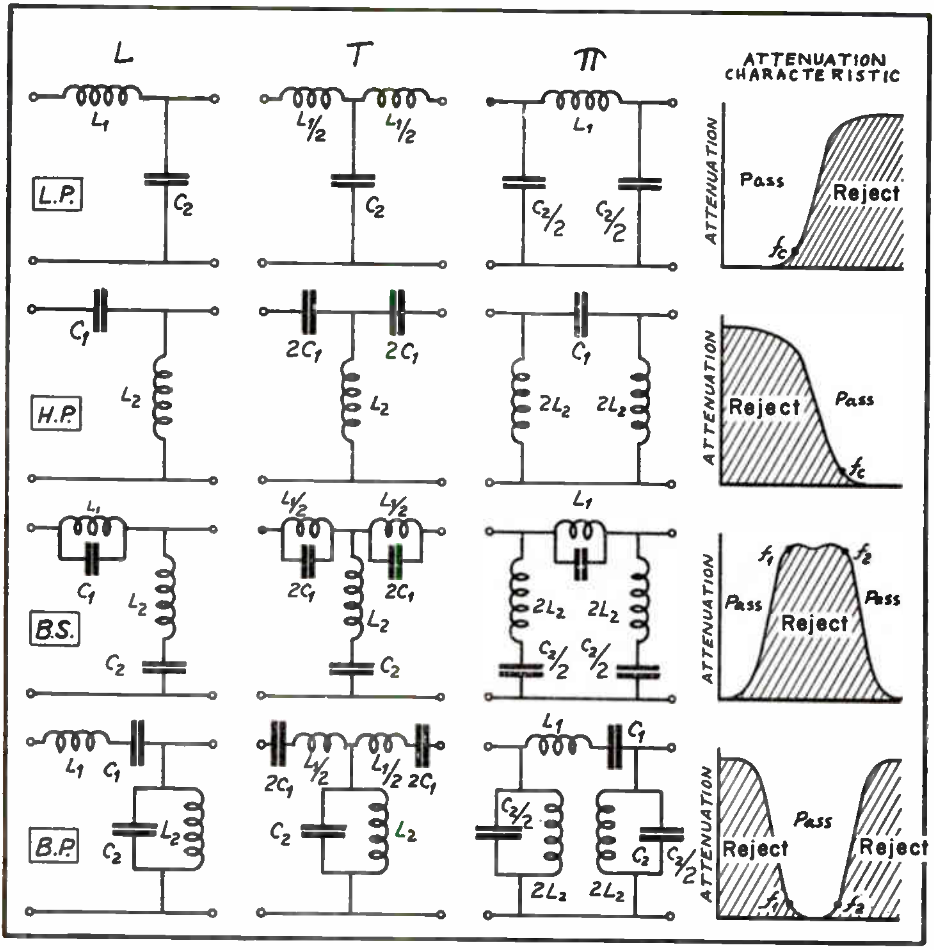


FIG. 41. The most common forms of L, T, and pi sections with their attenuation characteristics for low-pass, high-pass, band-stop, and band-pass filters.

quencies pass with little loss, and the overall response is improved. The two coils in series can be replaced by a coil of twice the inductance, as shown at B.

We may continue this arrangement for almost any number of sections. In all cases, however, the generator still works into a 500-ohm input impedance, and the impedance at the output continues to match the 500-ohm load.

In precisely the same manner, high-pass, band-pass, and band-stop multisection filters can be made. Wherever two arm capacities appear in series, however, the effective capacity is cut in half. These two capacitors, therefore can be replaced by a single capacitor. Where two coils appear in series, they can be replaced with a single coil of twice the inductance.

In cases where it is necessary to present a very high attenuation to one band of frequencies and, at the same

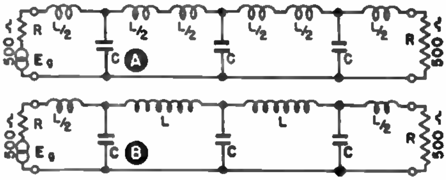


FIG. 42. Three low-pass T sections connected in tandem.

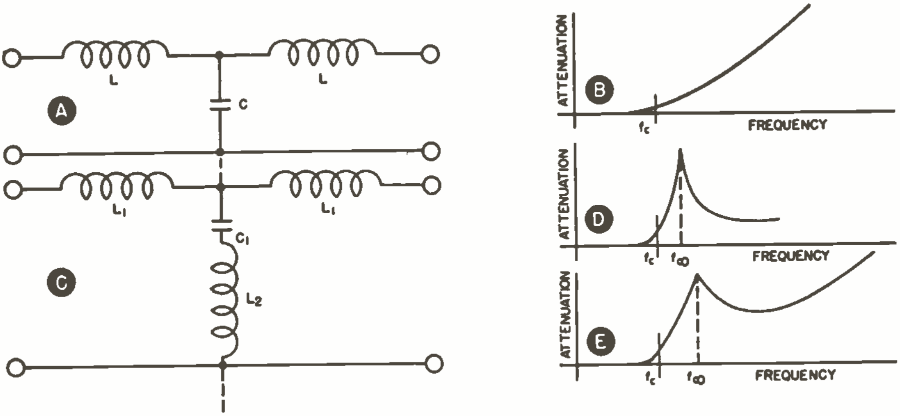


FIG. 43. A prototype section with high attenuation far from cut-off, and a derived section, with high attenuation close to cut-off, when put in tandem make a composite filter with a very sharp cut-off, and a high attenuation over the entire stop band.

time, pass an adjacent band of frequencies with little loss, we must use a filter with a sharper cut-off characteristic.

M-Derived Filters. Let us look at Fig. 43A. This is an ordinary low-pass T section, sometimes called a "constant K filter," with an attenuation characteristic like that shown in Fig. 43B. Since this is a basic filter section, it is often called a "prototype."

It is called a constant-K filter because of the fact that the product of X_L and X_C is constant at all frequencies. For example, at some frequency X_L may be 200 ohms, and X_C may be 50 ohms, and the product of the two is 10,000. At twice the frequency, X_L is 400 ohms, and X_C is 25 ohms and the product (the constant K) is still 10,000.

Let us modify the inductance and capacitance values of this prototype section so that an additional inductance L_2 can be placed in series with the capacitance C_1, as illustrated in Fig. 43C. If done properly, this does not change the section cut-off frequency, and it does not alter the response in the *pass band.*

In the *attenuation band,* however, we find that a startling change occurs. Since L_2 and C_1 form a series-resonant circuit, the section is "shorted out" at one frequency, and its response drops nearly to zero. This means that at one point in the stop band the attenuation is very high, reaching, theoretically, to infinity. In practical circuits, the attenuation does not reach infinity because of losses in the coil, but the response of such a section has a peak of great attenuation, as illustrated in Fig. 43D.

In choosing the value of L_1, C_1, and L_2 in the so-called derived filter, shown in Fig. 43C, a factor is used in special formulas to calculate their values. This factor, called the "M" factor, is determined by another formula based on how sharp the cut-off is to be. Since it is the sharpness of cut-off, or "M" factor, that determines the value of all L and C values in a derived filter, this arrangement is called an "M-derived" filter. Thus, an M-derived filter is one having infinite attenuation at some specific frequency, producing a sharper cut-off than a standard filter.

An M-derived section cannot be used alone, since after the infinite attenuation frequency, f_∞, is passed, the attenuation again drops to a low value. If, however, we connect a prototype and a derived section together in tandem, we realize a greatly improved filter performance. This means that we add the curve of Fig. 43B to that of Fig. 43D to get an over-all response like that shown in Fig. 43E.

Note that not only is the attenuation relatively high over the entire stop band, but also that the cut-off characteristic is much sharper. Notice also that the losses in the pass band near the cut-off frequency have been held to a minimum, which is impossible to realize by merely adding simple prototype sections together.

Fig. 43C does not represent the only practical type of derived filter section. The low-pass *pi-section* prototype in Fig. 44A, for instance, can be modified to appear as the derived section in Fig. 44B. The added capacitor C_2, in conjunction with coil L_1, now forms a parallel-tuned circuit, which at its resonant frequency serves to block the flow of current through the section. Here again, the result is an infinite-attenuation frequency in the stop band.

In constructing a multi-section filter, it is possible to use several derived sections. Furthermore, if different M values are used for each derived section, a separate infinite attenuation frequency for each section is obtained. In this way the over-all filter-response characteristic can have an extremely sharp cut-off, and very high attenuation at all points in the stop band. In general, filters that are made up of a prototype and one or more derived sections are called "composite" filters.

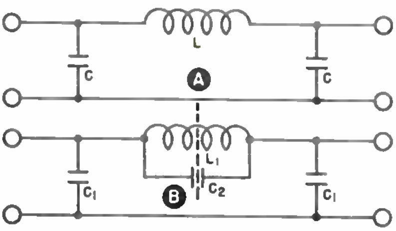


FIG. 44. A prototype low-pass pi section, and the corresponding M-derived section. Where the parallel-tuned circuit is resonant, the derived section has infinite attenuation.

INPUT-OUTPUT IMPEDANCE

Earlier we stated that symmetrical filter sections like the T and π sections in Fig. 41, possess input impedances that are *nearly* equal to the respective load resistances. Let us investigate this statement further.

Any symmetrical filter section has a characteristic or "iterative" impedance that is determined entirely by the values of inductance and capacitance. *It is only when the load resistance is made equal to this inherent characteristic impedance that the input impedance of a filter assumes an identical value.* In other words, for proper filter performance, it is desirable that we use source and load impedances that match the impedance of the filter itself.

Unfortunately, the characteristic impedance of a simple prototype filter section is not constant with frequency. Look at the low-pass T section in Fig. 41 to see why this is so. In the input terminals, the left-hand inductance arm $L_1/2$, and the shunt capacity C_2, together form a series-resonant circuit. Since these two are in resonance at the section cut-off frequency, the input impedance drops to a very low value at this point. In Fig 45, the solid curve shows how the characteristic impedance of a low-pass T section decreases rapidly from a nominal value for low frequencies to a theoretical zero value at the cut-off point.

On the other hand, the low-pass *pi section* in Fig. 41 resembles a split-capacitor parallel-tuned circuit, and it behaves like a parallel resonant circuit. For low frequencies, the section has a nominal characteristic impedance. As the frequency is raised, the input impedance increases, and at the cut-off point where the elements are

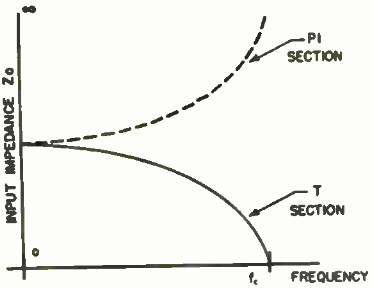


FIG. 45. The characteristic impedance of a prototype T section drops to zero at the cut-off frequency, and that of a pi section rises to a very high value.

resonant, the impedance approaches an infinite resistance. The dotted curve in Fig. 45 shows this typical impedance change for a pi section.

Although these two filter sections may have identical attenuation characteristics, their impedance variations are strikingly different. In general, it may be said that the impedance of any T section drops nearly to zero at a cut-off point, and that of any pi section rises to a very high value.

How can we match a source and load to a filter if the characteristic impedance of the filter varies so widely over the pass band?

In a great many filter applications where it is not necessary to work very close to the cut-off frequency, the change of filter impedance is not serious. In such cases, the impedance variation is ignored, and the source and load impedances are chosen to be equal to that of the filter at frequencies far removed from its cut-off frequency. This gives fair filter performance.

Under these conditions, however, the mismatch at cut-off substantially decreases the cut-off sharpness. For more accurate work, it is necessary to find a better method of matching the changing filter impedance. This *is done by a special type of T section to match a T section, or a special type of pi section to match a pi section,* called "half sections."

Terminating Half-Sections. Filters can be conveniently terminated by means of what are called half sections. Examples of half sections and how they perform are shown in Fig. 46. In A, we have shown the development of a half-section T. This filter is developed by dividing the T into two halves. Notice the value of the leg in the half sections is $2Z_2$, because the two impedances $2Z_2$ in parallel would have a value equal to Z_2, the impedance in the full T section.

Looking into terminals 1 and 2 of the left half of the T, we see the same basic arrangement as in the full T section. However, looking into the terminals 3 and 4 of the left side, the half section looks like the output of a π section filter.

Similarly, looking into terminals 1

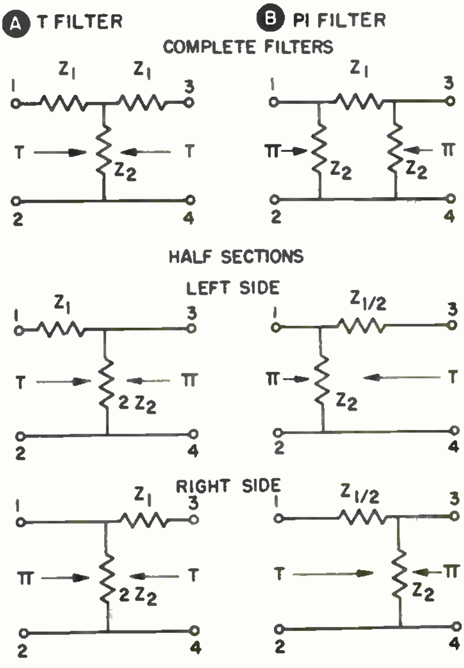


FIG. 46. How half-sections are developed from a T section (A) and a pi section (B).

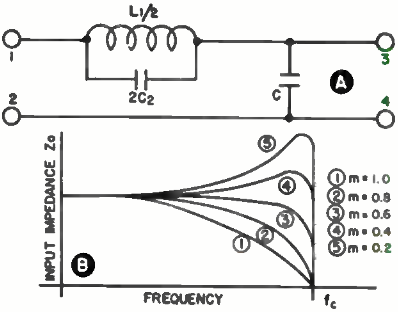


FIG. 47. A terminating half-section, and the variation of its characteristic impedance with frequency for different values of the multiplying factor M.

and 2 of the right half of the filter, we see the same basic configuration as we do at the input to a π section, and looking into terminals 3 and 4 we see it looks like a T filter.

The π filter can be broken down into two half sections as shown at B. Looking into terminals 1 and 2 of the left side, we see the circuit looks like the input to a π section, whereas looking into terminals 3 and 4 of this section we see a circuit similar to the output of a T filter. On the right side, looking into terminals 1 and 2, the circuit looks like the input to a T, and looking into 3 and 4, it looks like the output of a π filter.

Let us suppose that the M-derived pi section, shown in Fig. 44B, is split in half as indicated by the dotted line. If we consider only the right half, we have the half section shown in Fig. 47A.

Now looking into the terminals 3-4, this half section appears as a pi section. *Any full pi section, therefore, can be attached to these terminals without an impedance mismatch, since the two networks have the same impedance at all frequencies.*

Looking into the terminals 1-2, the half section resembles a T section, and the input impedance can be expected to drop to zero at the cut-off frequency. We find, nevertheless, that the manner in which this impedance drops to zero depends entirely upon the value of the multiplying factor M that we used to derive the total section in the first place.

If a value $M = 1$ is used, the half-section impedance varies like a prototype T section. This is shown by curve 1 in Fig. 47B. For lower values of M, the input impedance is more constant over the pass band. The input impedance variation for $M = 0.8$ and $M = 0.6$ is illustrated by curves 2 and 3, respectively. For still smaller values of M, let us say $M = 0.4$ and $M = 0.2$, the input impedance may rise to a high value before it drops abruptly to zero. See curves 4 and 5.

A value $M = 0.6$ gives the best performance, and results in a half-section input impedance that is very nearly constant over about 80% of the filter pass band.

We can use half sections like the one shown in Fig. 47A to match a constant-impedance generator to the variable impedance of a full pi section, or a number of pi sections in tandem. Furthermore, we can use an additional half section at the filter output to match the filter to a constant-impedance load.

A composite low-pass filter, made in this manner, is shown in Fig. 48A. The portion marked B is really the prototype pi section of Fig. 44A. The two terminating half sections, A and C, are made by splitting the derived pi section of Fig. 44B.

As two capacitors in parallel can be replaced by a single capacity, the composite filter can be simplified as shown in Fig. 48B.

Since two half sections have the same attenuation characteristics as a full-derived section, the over-all response of this filter looks like that shown in Fig. 43E. The half sections

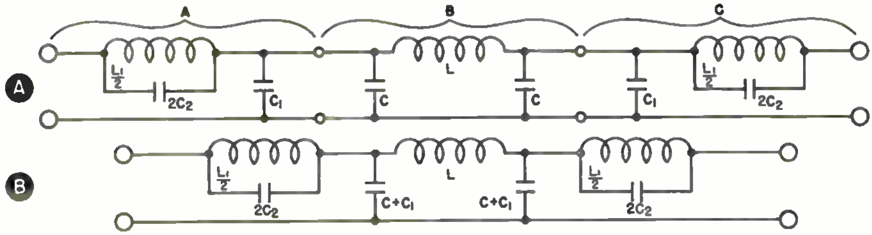


FIG. 48. A, a composite low-pass filter is made by using a prototype pi section and two constant-impedance terminating half-sections. B, the simplified filter, after combining parallel capacities.

have three uses: (a) they present a nearly constant impedance at each end of the filter; (b) they sharpen the cut-off response; (c) they supply an infinite attenuation at one point in the attenuation band.

In a similar manner, it is possible to construct half sections that accurately match a T-section filter. Thus, half sections, from the network shown in Fig. 43C, can be used to terminate a prototype T section like that shown in Fig. 43A. This gives the composite filter that is shown in Fig. 49A, which, in turn, can be simplified as shown in Fig. 49B. The half sections not only provide a good impedance match between source and filter, and between filter and load, but they also improve the general filtering action. The response curve for this composite filter is similar to Fig. 43E.

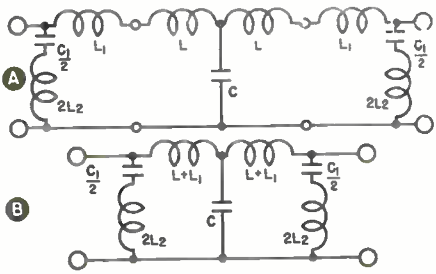


FIG. 49. The use of a T-section prototype with appropriate half sections to make a low-pass composite filter. The network is simplified by replacing two inductances in series, with a single inductance equal to their sum.

DESIGNING FILTERS

We have seen that it is the arrangement of components in a network that determines its general response characteristics. By properly arranging coils and capacitors we can make a network function as a low-pass, high-pass, band-pass, or band-stop filter. However, it is the values of the components that determine just where within the frequency range a filter will pass or reject signals. Therefore, to construct a filter we must be able to determine the values for components as well as their arrangement.

Before we can design a filter for some specific application, we must know which frequencies are to be passed, and which are to be rejected, and the amount of attenuation of unwanted frequencies necessary. In other words, we must know whether it is to be a low-pass, high-pass, band-pass, or band-stop filter. We must know the cut-off frequency of a low-pass or high-pass filter. For band-pass or band-stop filters, we need to know both the upper and lower frequency limits of the band to be passed or rejected. We should know how much attenuation of undesired frequencies is necessary, as it may be necessary to use a multi-section filter to obtain enough attenuation and a sufficiently sharp cut-off.

Let's assume, for example, that we want to construct a filter that will pass all frequencies between 0 and

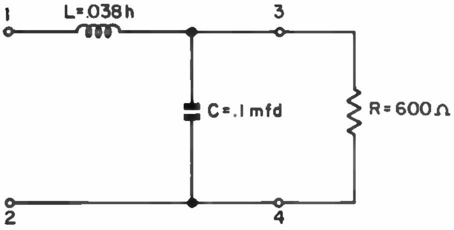


FIG. 50. Low-pass constant-K, L filter.

5000 cycles and attenuate all frequencies above 5000 cycles. Since we wish to pass low frequencies and attenuate high frequencies, we will want a low-pass filter. We know that we can obtain low-pass characteristics by using a series coil and a shunt capacitor in an L network as shown in Fig. 50. Next, we must determine the particular values of inductance and capacitance that will give us a cut-off frequency of 5000 cycles.

The L Filter. To do this, we apply our circuit values to special formulas that have been derived for filter network computation. For a low-pass filter the capacitance is found from the formula: $C = \frac{1}{\pi\ fc\ R}$; and, the inductance from the formula:

$$L = \frac{R}{\pi\ fc.}$$

In both of these formulas R is the impedance of a purely resistive load and fc is equal to the desired cut-off frequency in cycles per second. If we apply these two formulas to our circuit in Fig. 50, we find that the inductance equals:

$$L = \frac{R}{\pi\ fc} = \frac{600}{3.14 \times 5000}$$

$$= \frac{600}{15{,}700} = .038 \text{ henrys}$$

and, the capacitance equals:

$$C = \frac{1}{\pi\ fc\ R} = \frac{1}{3.14 \times 5000 \times 600}$$

$$= \frac{1}{15{,}700 \times 600} = \frac{1}{9{,}420{,}000}$$

$$= .0000001 \text{ farad or, .1 mfd.}$$

Thus, a coil of .038 henrys and a capacitor of .1 mfd arranged in an L network with a load resistance of 600 ohms gives us a low-pass filter with a cut-off frequency of 5 kc.

Converting an L Filter to a T or Pi Filter. We know from our previous discussion of filters that we can improve the cut-off curve for our filter and match impedances by converting the L network to a T or pi network. To do this, we simply use two coils of half the inductance value for the T filter as shown in Fig. 51A. Or, if we prefer the pi filter, we could use two capacitors of half the capacitance as shown in Fig. 51B. The choice of using either a T or a pi filter is simply a matter of convenience, as they give exactly the same performance. The

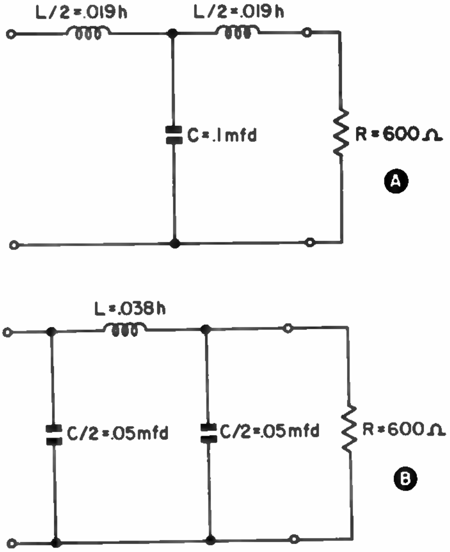


FIG. 51. Low-pass constant-K filter converted to T network, A; low-pass constant-K filter network converted to pi network, B.

choice is usually based on availability of components.

M-Derived Filter. The filter that we have just computed is a prototype, or constant-K filter. We know from the previous section on filter principles that we can get a sharper filter cut-off and obtain better impedance matching throughout the pass band by using an M-derived filter. An M-derived T section is formed by inserting an inductor in series with the leg capacitor of a prototype T section as shown in Fig. 52.

The addition of this new inductance causes the attenuation to rise sharply to a very high value as soon as the cut-off frequency is reached. This is due to the fact that the leg of the filter is designed to be series resonant at some frequency slightly above cut-off. When resonance occurs, nearly all the current is shorted around the load, giving us almost infinite attenuation.

In an ordinary constant-K filter, when the cut-off frequency is reached, the attenuation increases gradually to some maximum value as the frequency is increased above cut-off. In the M-derived filter, we actually make the attenuation curve above cut-off rise sharply by making the frequency of maximum attenuation occur nearer the cut-off frequency than it normally does. Therefore, the sharpness of the cut-off curve depends on the location of the frequency of maximum attenuation with respect to the cut-off frequency.

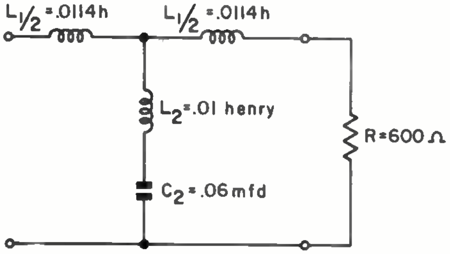


FIG. 52. Low-pass constant-K, L filter converted to M-derived T network.

The factor M from which the M-derived filter gets its name relates to the ratio of this frequency of maximum attenuation, f∞, and the cut-off frequency, fc. For a low-pass filter, M is found from the following formula:

$$M = \sqrt{1 - \left(\frac{fc}{f\infty}\right)^2}$$

For a high-pass filter, M is found from the formula:

$$M = \sqrt{1 - \left(\frac{f\infty}{fc}\right)^2}$$

Converting a Constant-K Filter to an M-Derived Filter. To change an ordinary constant-K filter to an M-derived filter, we add the proper reactance component to the filter and change all the values by an amount depending on the value of M. To see how this works, let's convert the low-pass constant-K, T section, shown in Fig. 51A to the M-derived filter shown in Fig. 52.

The first thing we must do is select a value for the frequency of maximum attenuation, f∞. If we make the frequency of f∞ equal to 6250 cycles, we can then find the appropriate value of M from the formula:

$$M = \sqrt{1 - \left(\frac{fc}{f\infty}\right)^2} = \sqrt{1 - \left(\frac{5000}{6250}\right)^2}$$

$$= \sqrt{1 - .8^2} = \sqrt{1 - .64}$$

$$= \sqrt{.36} = .6$$

To find our new value L to use for our arm coils L_1, we simply multiply our original value of L by our value of M. This gives us:

$$L_1 = LM$$

$$= .038 \times 6$$

$$= .0228 \text{ henrys.}$$

We divide this new value L_1 by 2 to obtain the correct value for each of our arm coils. Thus our new arm inductances are .0114 henrys each.

Our capacitor C_2 is also determined by multiplying the original value of C by M. Or

$$C_2 = CM = .1 \times .6 = .06 \text{ mfd.}$$

The value of the inductance L_2 that we inserted in the leg of our network is found by applying our original value of L in the following formula:

$$L_2 = \frac{1 - M^2}{4M} \times L$$

$$= \frac{1 - .36}{2.4} \times .038$$

$$= \frac{.64}{2.4} \times .038 = \frac{.02432}{2.4}$$

or, approximately .01 henry.

If we prefer, we can use the M-derived pi section shown in Fig. 53. In this filter, the value of our capacitor C_2 used in the T section is divided by 2 to form the two legs of our M-derived pi section. We have a new capacitor C_1 in parallel with our inductance L_1 to form our filter arm. The value of L_1 is the sum of the two arm inductances $L_1/2$ used in the T section. The value of C_1 is found by substituting the original value of C that we used in our L filter in place of the value of L in the formula:

$$L_2 = \frac{1 - M^2}{4M} L \text{ or,}$$

$$C_1 = \frac{1 - M^2}{4M} C = \frac{.64}{2.4} \times .1$$

$$= \frac{.064}{2.4} = .026 \text{ mfd.}$$

These formulas, along with those used for high-pass, band-pass, and band-stop filters, are shown with their appropriate circuit diagrams in Fig. 54. Notice that in these circuits and formulas, the subscript 1 indicates an arm reactance and the subscript 2 is used for the leg components where necessary to avoid confusion between reactances. Although we have shown the formulas for M-derived, high- and low-pass filters, we have not shown them for band-pass and band-stop filters. The m-derived band-pass and band-stop filters become much too complex for anyone except filter design specialists.

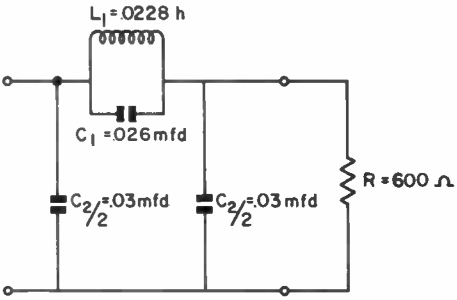


FIG. 53. Low-pass constant-K, L filter converted to M-derived pi network.

In these formulas, the units for F, L, C, and R are in cycles-per-second, henrys, farads, and ohms, respectively.

Factors Affecting Design. The standard equations for constructing filters are based on lossless elements which are pure reactances. Thus, in actual practice, the response of a filter may be somewhat different from what was expected. How great this difference will be depends on the care that was exercised in choosing the parts and in constructing the filter.

A high-Q coil has very little loss, since it is mostly inductance and very little resistance. When a lower-Q coil is used, the losses are increased. Also, when a low-Q coil is used in a tuned circuit, the response of the circuit is broadened. It will no longer be as sensitive to frequencies at or near the resonant frequency.

There is always some capacitance between the adjacent turns of the coil winding, and this lowers the Q and increases the losses. Coils wound with wire insulated with a material having

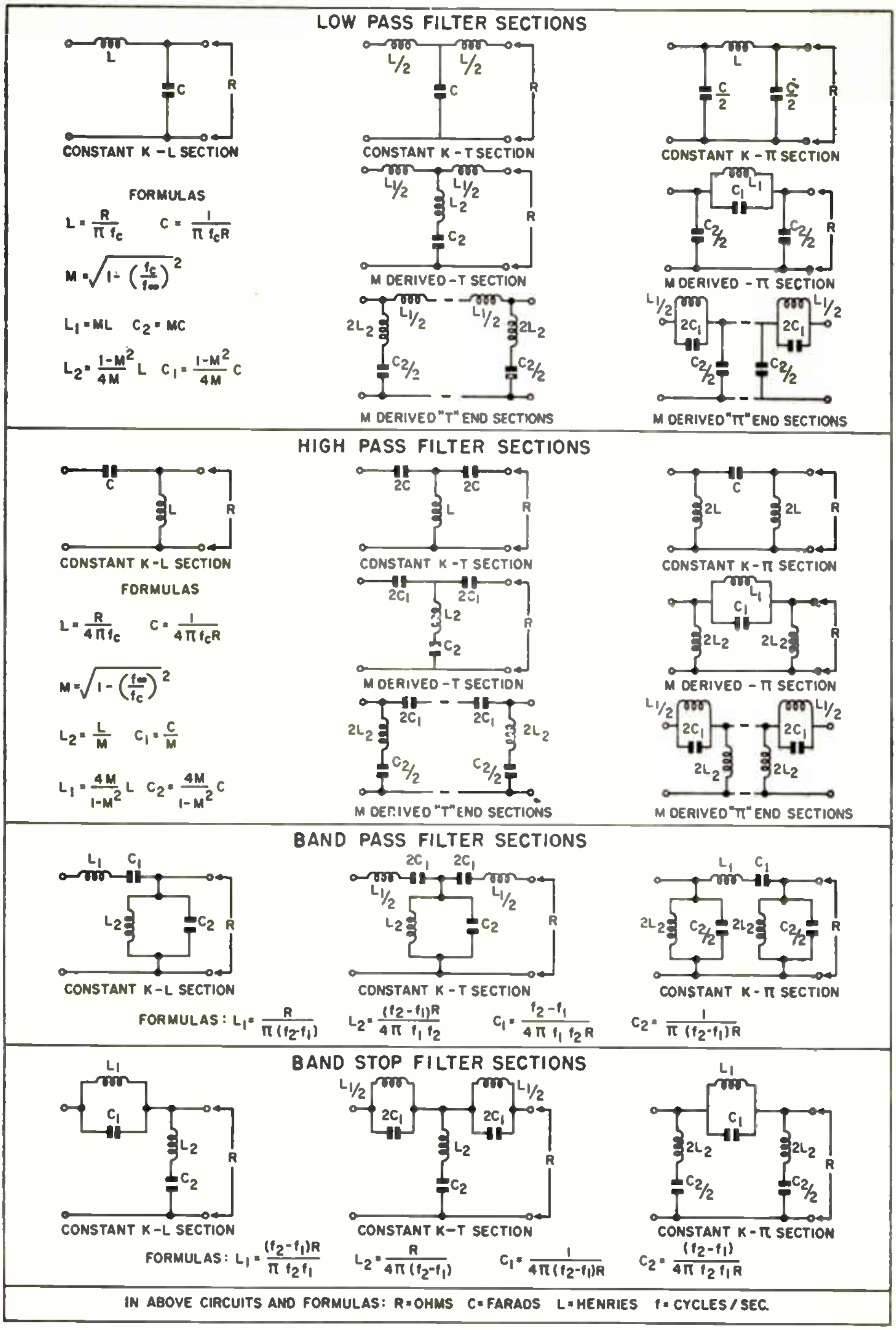


FIG. 54. Basic filter circuits and formulas.

low dielectric hysteresis loss are the best from this standpoint.

When two coils or two circuits are physically near each other, usually some coupling exists, although none may have been intended. The magnetic field about one coil or circuit induces a current in the other. Also the metallic parts of the two circuits form a small capacitance through which energy may be transferred. The Q of a coil is lowered by the loss of energy coupled out of it, and the response of the filter may be seriously altered.

This effect can be minimized by the proper placement of the parts (physical separation, mounting coils at right angles to each other, etc.) and by careful shielding. Shielding a coil lowers its inductance and also results in an energy loss because of the resistance of the shield, which increases the effective resistance of the coil. These effects lower the Q of the coil, but the reduction will be slight if the spacing between shield and coil is equal to at least the coil diameter at the coil ends and at least half this distance at the coil sides.

At power supply or audio frequencies, eddy current losses in iron-core coils may be reduced by constructing the cores of thin metal sheets called laminations. At higher frequencies, it is not practical to try to make laminations small enough or thin enough for use in coil cores. Coils used at these frequencies are air-core coils or have cores made from powdered iron mixed with a suitable binder The binder holds the particles together so that they can be shaped to the form desired and also insulates them from one another to prevent eddy currents. A type often used in communications equipment is the toroid coil. It is a single-layer or multi-layer coil wound on a doughnut-shaped powdered-iron core. An advantage of this type is that, so long as the core is unbroken, all of the lines of force are in the core and none outside. As a result, shielding is seldom necessary to prevent coupling between a toroid coil and another coil or circuit.

MEASURING FILTER RESPONSE

When checking filter response, great care must be exercised in setting up the equipment to avoid any stray coupling or leakage. All the units in the test setup must be bonded together and a good common ground provided.

Insertion Loss. The insertion loss of a filter is simply the loss in output, usually expressed in db, caused by inserting a filter in a circuit When the filter is to be tested before installa-

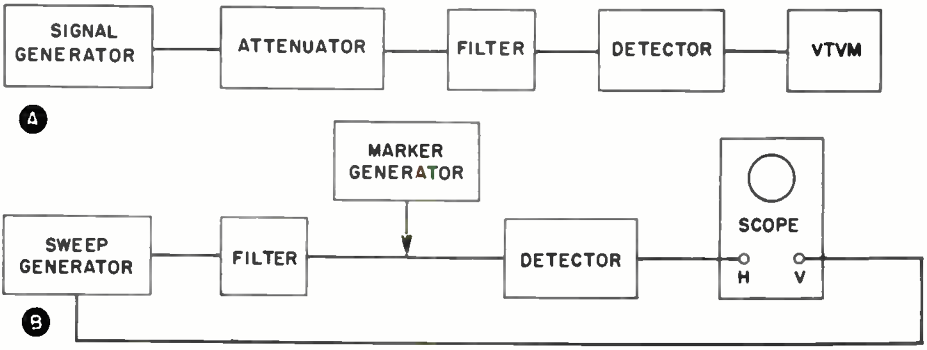


FIG. 55. Test setups for measuring (A) insertion loss, and (B) frequency response of a filter.

tion, a setup such as that in Fig. 55A can be used to measure this insertion loss. The signal source can be a signal generator, with or without modulation. For low frequencies, the output meter may be a db meter or a vtvm. For rf frequencies, a vtvm should be used. In some cases, the needed output is most conveniently obtained by feeding the filter output to a good receiver.

Using the lowest signal level that provides a usable indication with the filter in the circuit, the output is noted. Without changing the amplitude of the input signal, the filter is removed from the circuit, the circuit is reconnected, and the output is noted. The difference in the two readings is the insertion loss of the filter.

The attenuator at the input of the filter is provided to reduce the input signal to the lowest amplitude that will give a usable indication on the meter with the filter in the circuit. Unless the input signal is kept as low as possible, there may be so much leakage across the filter that the results obtained are inaccurate.

It is important for the shielding for the test setup to be as good as it can be made, particularly when dealing with rf frequencies. With rf frequencies, it is difficult to obtain accurate results at best, and without adequate shielding, it becomes impossible.

In most cases, the most satisfactory check of the insertion loss of a filter is simply to try the filter in the circuit and see if it does the job for which it was designed. Ordinarily, you'll know how much attenuation of unwanted frequencies is necessary and how much attenuation of wanted frequencies can be tolerated. If the circuit works satisfactorily after the filter is installed, you won't usually need to know or care exactly what the insertion loss measures.

Filter Response. The response curve of a filter can be checked either by a point-to-point method or by using a sweep signal generator and an oscilloscope to obtain a visual indication of the response curve. In the first method, the signal generator is connected to the input of the filter, and its frequency set to some point within the expected pass band. An output meter is connected to the output circuit and the signal generator set to give a convenient indication. Then the signal generator is set to the lowest frequency at which there is any response, and the frequency is advanced in equal steps, and the output at each frequency recorded. These readings are plotted on graph paper in db, the frequency being plotted horizontally and the output vertically.

A more convenient method of checking response is shown in Fig. 55B. Here the response curve can be observed and the effects of any adjustments noted. A marker generator set to the proper frequency and loosely coupled to the filter can be used to inject a pip at the cut-off frequency or any other point of interest within the band.

Lesson Questions No. 29

Be sure to number your Answer Sheet 29CC.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of lessons before new ones can reach you.

1. What are two reasons for using attenuators?
2. Use the table in Fig. 9 to compute the values of R_A (the arm resistors) and of R_L (the leg resistor) in a T-type resistive pad in which the output and input are both 60 ohms, and attenuation is 8 db.
3. Complete the following: A minimum loss L pad is used to (a) match unequal impedances; (b) provide attenuation and maintain an impedance match between equal impedances; (c) filter out undesirable harmonics.
4. What requirement must a network have before it can be considered a filter?
5. Name the four basic types of filter circuits.
6. Name the filter circuit you would use if you wanted to pass only the band of frequencies between 3,000 cycles and 10,000 cycles.
7. If we connect three low-pass T sections in tandem, what effect will this have on the attenuation of the unwanted frequencies as compared with a single low-pass, T-section filter?
8. What information must you have before you can design a filter circuit?
9. Compute the values of L and C in a simple, constant-K, L-section, high-pass filter having a characteristic impedance of 100 ohms and a cut-off frequency of 100 cycles.
10. Complete the following: A long line, such as a telephone line (a) attenuates the low frequencies more than the highs; (b) attenuates the high frequencies more than the lows; (c) attenuates the highs and lows about equally.

"WISHERS" AND "DOERS"

How often have you said, "I wish I had more money?" Thousands of times, possibly. But do you realize that if you are living in a town of, let us say, 5,000 inhabitants, there are exactly 4,999 others in your town who are saying exactly the same thing?

And yet, of these 5,000 "wishers," only about 100 are going to do something about it. The others are going to continue being "wishers."

Now, any man who shows enough "get-up-and-go" spirit to undertake this course proves that he is not a mere "wisher." When you enrolled, you showed that you wanted to be a "go-getter." Your job now is to keep going forward on the road you have mapped out for yourself.

Every lesson in this course, every job you work hard to get, is a step along this road. So don't let yourself wish that the lessons were easier, or that you could become successful without studying, or that jobs would come looking for you. Stay out of the class of the "wisher," and stay in the class of the "doer."

J. M. Smith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ACHIEVEMENT THROUGH ELECTRONICS

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OPERATIONAL AMPLIFIERS

K309

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OPERATIONAL AMPLIFIERS

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STUDY SCHEDULE

☐ 9. Answer the Lesson Questions.

☐ 10. Start Studying the Next Lesson.

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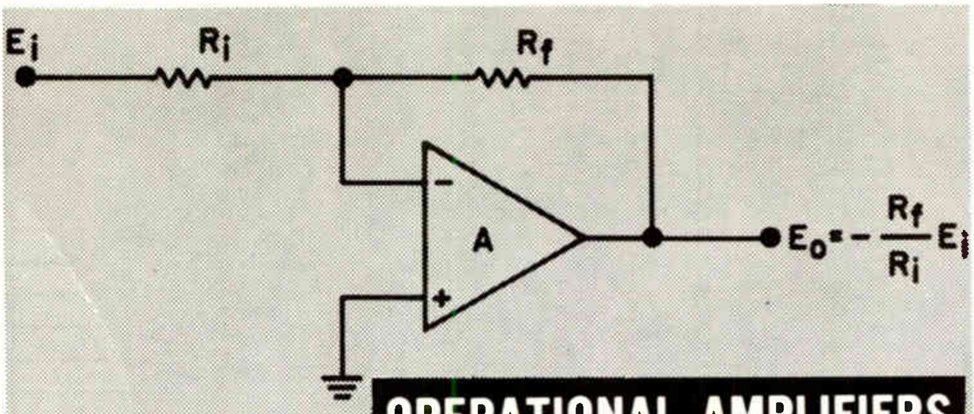


OPERATIONAL AMPLIFIERS

This lesson is your detailed study of one of the most important types of amplifiers used in electronics today – the operational amplifier. Its application is almost unlimited because of its great versatility. This type of amplifier is also the key element in all analog computers. The operational amplifier, in its numerous configurations, can help perform many mathematical operations.

Since you previously had a brief introduction to the operational amplifier, you should already have a basic idea of what it is and how it is used. However, this lesson will expand your basic knowledge of this important circuit.

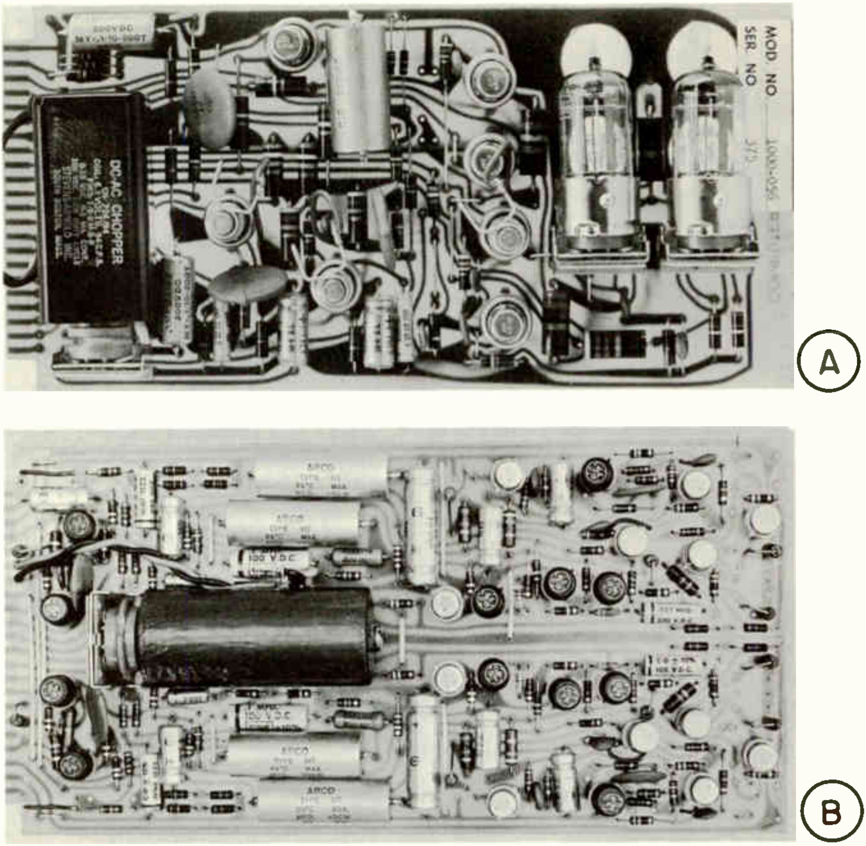
Like any other amplifier, an operational amplifier has an input and an output. Amplifiers generally increase the level of the input signal and present it at a higher level at the output; therefore the operational amplifier circuit has gain and amplifies small signals that are applied to its input.

An operational amplifier is basically a linear amplifier which accurately reproduces the shape of the input signal. However, it possesses special characteristics which set it apart from more conventional amplifiers and permit it to be a much more versatile circuit.

The term "operational" came about because of the early use of an amplifier to perform mathematical operations. Today these amplifiers still perform their original operations, but they have also become adapted to be used for many other functions.

Operational amplifiers, commonly called op amps, come in many different forms. For example, the very earliest types of op amps were made with vacuum tubes. A typical vacuum tube op amp is shown in Fig. 1A, where you can see the vacuum tubes, resistors and capacitors mounted on a printed circuit board. The seven circular metallic devices are miniature vacuum tubes. The large rectangular object is a mechanical chopper. While you may still encounter tube type op amps in some older equipment, the majority of operational amplifiers in use today are transistorized units. A transistorized operational amplifier is shown in Fig. 1B. The large cylinder is a chopper. Again, all of the components are mounted on a printed circuit board.

Today integrated circuit operational



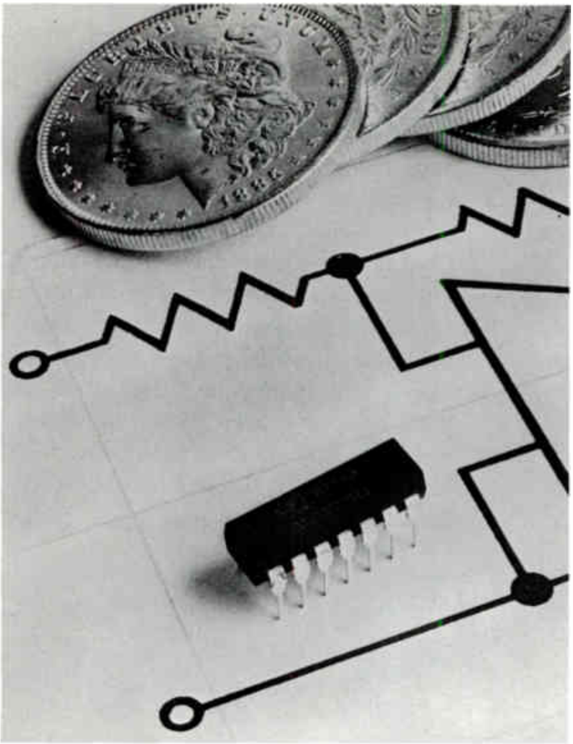
Courtesy Hybrid Systems, Inc.

Fig. 1. A tube type operational amplifier (A) and a transistorized operational amplifier (B).

amplifiers are rapidly replacing the discrete component types in many applications. An integrated circuit operational amplifier is an entire miniature transistor amplifier constructed on a single chip of silicon, in much the same way a transistor is made, and housed in a small multi-lead package like that shown in Fig. 2. Notice the extremely small size of this amplifier. Such an amplifier is as sophisticated as and generally superior to the tube and transistor operational amplifiers of Fig. 1. Later in this lesson we will take a look at some of the circuit details of transistor operational amplifiers. The emphasis in this lesson will be on the transistor type circuit; these are the circuits you will most encounter in your work, in both discrete and miniature integrated circuit form.

An amplifier has to have certain distinct characteristics before it can be called an op amp. The extent to which it meets these requirements indicates how good an operational amplifier it is. Even though the perfect operational amplifier cannot be made, its value is based on how closely it can approach the characteristics of the ideal amplifier.

One characteristic of an ideal oper-



Courtesy Texas Instruments

Fig. 2. Integrated circuit operational amplifier in a dual in-line package.

ational amplifier is that it must be a dc amplifier, that is, it must amplify slowly varying signals or dc levels. In order to amplify or pass very low frequency ac signals or dc levels, direct coupled circuitry is usually used.

The ideal op amp should also have a zero output voltage if the input voltage is zero. Many amplifiers do not have this characteristic. With a zero voltage input signal applied, many amplifiers have a fixed dc output voltage. When the input signal is applied the output varies above and below this fixed dc output level. Although this is not detrimental to circuit performance, it is more convenient for an op amp to have the output voltage zero when the input is zero. If only ac signals are to be used, then a capacitor can remove this output level. However, remember that we want our op amp to have the capability of measuring, or amplifying, dc signals.

Thirdly, the ideal op amp must have very high input impedance. When connected to a source of signal voltage, its impedance is so high that it will not draw any current from the source; its input impedance is infinite.

Ideally the op amp must also have low drift. In other words, it must be a perfect dc amplifier whose output does not vary with changes in circuitry or surroundings.

The ideal op amp will have a zero output impedance. This means that if any load resistance is connected to it, the output will not be loaded down since there is no internal circuit resistance present. With a zero output impedance, the op amp is a perfect voltage source with an output voltage that remains constant regardless of the load connected to it.

Another ideal factor is minimum power consumption. A good op amp will not draw a lot of current from its power supplies during operation.

* Optimally, the amplifier should be a differential amplifier. Op amps can be constructed with a single-ended rather than a differential input. However, most operational amplifiers you encounter will be differential amplifiers.

In order to function at its best, the op amp must have very high voltage gain. A minimum figure is 1000 (most have gains higher than 10,000).

As noted before, the perfect op amp does not exist. Even so, actual operational drawbacks are hard to find. Just what degree of departure from the ideal that can be tolerated depends strictly upon the amp's specific application. Each requirement for an op amp will have to be investigated to determine those characteristics needed or desired. For example, a particular requirement may call for an op amp with input impedance greater than one megohm, voltage gain greater than 25,000 and output impedance less than 200 ohms. Even though these characteristics are less than ideal, they accurately satisfy the requirements of the particular application.

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Fundamentals

An op amp is nothing more than a combination of some of the individual amplifier circuits you studied before. For example, a typical op amp may consist of a differential amplifier direct coupled to an emitter-follower which drives a complementary symmetry output circuit. All of these amplifiers and fundamentals you learned in previous lessons. Here we will collect this information and show you how an op amp is formed.

To begin, however, we will emphasize only the fundamentals of the op amp. Once you understand the overall concept, you can begin to study the detailed circuit operation.

In most of this lesson you will see the op amp designated by the symbol in Fig. 3. The letter A inside the triangle designates the gain of the amplifier.

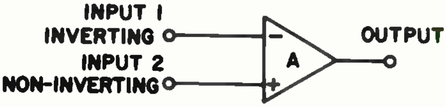

Fig. 3. Basic operational amplifier symbol.

This op amp has two inputs; therefore, it is a differential amplifier. The – and + signs on the inputs designate the inverting and non-inverting input lines. Input 1 is designated with a negative sign, indicating that it is the inverting input. If a signal is applied to input 1, the output will be 180° out-of-phase with the input. When input 1 is used, the op amp is an inverter. Input 2 is designated by a positive sign; it is the non-inverting input. Any input signal applied here will appear in the same phase in the output.

If we apply an input signal to the amplifier, an output signal will be generated. The input signal will be amplified by an amount equal to gain A of the amplifier. If the input signal is very small, it will appear greatly enlarged at the output because of the high gain.

If the input signal to the op amp is too high, the amplifier output will be clipped. For example, if we apply a 1 volt input signal to an op amp with a gain of 50,000, our output should theoretically be equal to the input multiplied by the gain, or 50,000 volts.

This, of course, cannot actually happen. The output of any amplifier is limited by the power supply voltages. Most op amps are powered with both positive and negative voltages. A typical transistor op amp, for example, uses power supplies of +15 and –15 volts. For this reason the output cannot swing any greater than ±15 volts (for a sine wave signal, no more than 30 volts peak-to-peak). Should the input voltage be too high and try to cause an output voltage beyond the power supply capability of the amp, the output signal will be clipped on both positive and negative peaks. This is due to the saturation of the output transistors.

Since its gain is so high, the op amp can be used satisfactorily with only very low level signals. The gain is also unstable, varying greatly from one amplifier unit to the other of the same type. One operational amplifier may have a gain of 25,000 while an identical amplifier may have a gain of 35,000. While the circuits of the two amplifiers may be identical, various characteristics of the components could cause large gain differences. For many applications this is a disadvantage.

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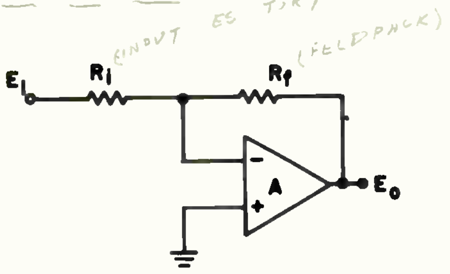
To overcome this problem we generally use negative feedback with op amps; some of the output voltage from the amplifier is fed back to the inverting input through a resistor. As you learned in the previous lesson, negative feedback reduces the overall gain of an amplifier and at the same time stabilizes it. It also improves frequency response

The most common op amp circuit is shown in Fig. 4. Here the non-inverting input to the amplifier is grounded. This eliminates the differential characteristics of the amplifier so we can use it as a single-ended circuit.



$$A = -\frac{R_f}{R_i} \qquad E_o = -\frac{R_f}{R_i}(E_i)$$

Fig. 4. Standard operational amplifier circuit.

Negative feedback is provided by the feedback resistor R_f connected between the output and the inverting input. An input resistor designated as R_i is also connected to the inverting input. The free end of this resistor is the input to the circuit. With this arrangement the gain of the circuit is determined strictly by the ratio of the feedback to input resistances: gain = R_f/R_i.

Negative feedback makes the gain of the circuit completely predictable. To control or set the gain of this amplifier, we simply select appropriate values of feedback and input resistors. For example, if the feedback resistor R_f is equal to 100K-ohms and resistor R_i is equal to 10K-ohms, the gain of the circuit is 100K/10K = 10. Keep this fact in mind.

Another important characteristic of this circuit is that it is an inverter. Since we are using the inverting input of the amplifier, the output signal will be 180° out-of-phase with the input signal. When expressing the gain, a negative sign is indicative of this inversion.

In Fig. 5 we show all the currents and voltages in a standard op amp circuit. The input resistor is designated R_i while the feedback resistor is designated R_f. Current flowing in the input resistor is designated as I_i; current flowing in the feedback is I_f. I_b is the current flowing into the input. It is generally the base current of a transistor. The amplifier input voltage, or that voltage appearing directly at the input of the amplifier, we label E_b. The input voltage to the entire operational amplifier circuit is designated as E_i. The output voltage is E_o.

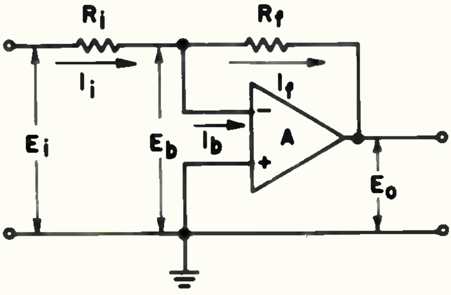


Fig. 5. Currents and voltages in an op amp.

Using these currents and voltages and some simple Ohm's Law relations, let's again see how the gain formula for this circuit is obtained. First of all, we know that the output is equal to the input voltage multiplied by the gain. The output voltage E_o, then, is equal to E_b times $-A$. To find the value of E_b, we algebraically rearrange the formula to produce $E_b = -E_o/A$. Remember that the negative sign indicates inversion.

From earlier lessons you found that the voltage across any component is equal to the difference in the two voltages at the ends, with respect to ground. For example, if we measure 10 volts at one end of a resistor and 7 volts at the other, the voltage across that resistor is 3.

With this in mind, we can write a formula for the voltage across the input and feedback resistors. The voltage across the input resistance R_i is equal to $E_i - E_b$. The voltage across the feedback resistor R_f is equal to $E_b - E_o$. Knowing the voltages across the resistance, we can write a simple Ohm's Law expression for the current through each resistance. For example, the current I_i through the input resistor is equal to the voltage across it $(E_i - E_b)$ divided by R_i. The current I_f through the feedback resistor is equal to the voltage across it, $(E_b - E_o)$ divided by the resistor R_f.

Refer to Fig. 5, where the current flowing into the amplifier is I_b. If we assume that our op amp is perfect and has an infinite input impedance, we can conclude that it will not draw current from the input source; therefore, $I_b = 0$. Because of this the input current I_i also flows in the feedback resistor R_f. This means that the input and feedback currents are equal. We can write a simple expression for their equivalence:

$$I_i = I_f$$

or

$$\frac{E_i - E_b}{R_i} = \frac{E_b - E_o}{R_f}$$

Now, let's make another assumption based on the characteristics of an ideal op amp. Earlier we said that the input voltage E_b is equal to the output voltage E_o divided by the gain $-A$. The gain is so high that the input voltage E_b is extremely small. It is so small, in fact, that for all practical purposes we can call it zero. If we assume a zero value for E_b, we can remove E_b figures from the formula. Thus simplified it reads:

$$E_i/R_i = -E_o/R_f$$

From this we can find that the output voltage is equal to the gain of the circuit, the ratio of the feedback to input resistances, multiplied by the input to the circuit:

$$E_o = -\frac{R_f}{R_i}(E_i)$$

The negative sign again indicates inversion. As you can see, we have used only algebra and Ohm's Law to determine the gain of the op amp circuit.

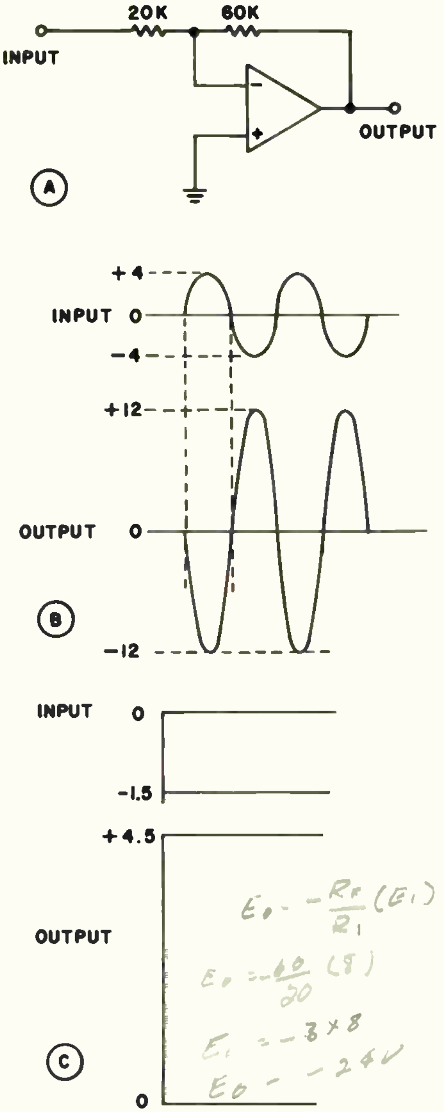
Keep in mind several things. We assumed that the input current to the amplifier was zero. As a result, we neglected it. We also assumed that the gain of the amplifier was infinitely high. Even though we had to use these assumptions to approach the ideal, the formula given will be quite satisfactory for an op amp with a gain of 1000 or more.

There is one very important characteristic of the op amp in its standard configuration. As mentioned earlier, the input impedance to a good op amp is very high. This, of course, is true in the circuit of Fig. 5. However, the input impedance of the circuit is not the same as the input impedance of the amplifier. The feedback and input resistor connections determine what the input impedance will be.

The input voltage to the amplifier (E_b) is near 0 volts, or ground. Since E_b gives the same effect as a true ground, we can more precisely call it a virtual ground. This is the case of the junction of the feedback and input resistors at the inverting input of the amplifier in Fig. 5. This point is called the summary junction because it is the input and output of all the currents in the circuit.

Since we can consider the right hand of resistor R_i as being connected to ground, the input impedance of the amplifier circuit is equal to the value of resistor R_i. If R_i is 100K-ohms, then the input impedance of the circuit is also 100K-ohms. This is a usually desirable characteristic of this circuit because the exact input impedance to the circuit is known. In the case of the input impedance of the amplifier, we do not always know its exact value. Of course, if it is high enough it will not affect the circuit. Therefore, we need not always be concerned with it. However, the input resistance produced by resistor R_i often is not high enough to suit the application. In that case we have to make a compromise in the gain of the circuit by adjusting the values of R_f and R_i to give an appropriate input resistance.

Now let's see how a typical op amp circuit works. Fig. 6A shows an op amp with a 60K feedback resistor and a 20K input resistor. From this circuit you know that the input impedance is equal to 20K, the value of the input resistor. We can figure the gain of the circuit by finding the ratio of the feedback to the input resistance (60K/20K = 3). The circuit will amplify an input signal by a factor of three.



$E_0 = -\frac{R_f}{R_1}(E_1)$

$E_0 = -\frac{60}{20}(8)$

$E_i = -3 \times 8$

$E_0 = -24V$

Fig. 6. A conventional op amp circuit (A), typical ac input-output waveforms (B) and dc input-output levels (C).

Fig. 6B is a sine wave input signal of 8 volts peak-to-peak. If we apply the peak signal voltage to the input of the amplifier circuit, the output shown in Fig. 6B will be produced. Notice that the amplitude of the output is 3 times that of the input. The peak output voltage is 12 volts or 24 volts peak-to-peak. Notice also that the input and output signals are 180° out-of-phase, designating the inverting characteristic of the op amp circuit.

The op amp can also amplify dc signals. Fig. 6C shows a negative 1.5 volt input applied to the amplifier circuit. This is amplified and inverted to produce an output of +4.5 volts. If the input signal is removed from the circuit and the input line grounded, then the output of the amplifier should be 0 volts. Because of unbalanced amplifier circuits, the output may be only near 0 volts. In most op amps it is necessary to reduce the output to exactly zero; some form of compensating voltage must be applied to the circuit to bring the output voltage to zero.

A popular variation of the circuit shown in Fig. 6 is one where both the input and feedback resistors are equal. Since these resistors are equal, the gain of the circuit is equal to 1. We say that the amplifier has unity gain. An op amp connected this way is called a unity gain inverting amplifier. Since it has no gain you might think that it has no application. However, it is widely used where we want to maintain the amplitude level of a signal and at the same time obtain 180° phase inversion. The circuit acts as a good isolation amplifier with a relatively high input impedance and low output impedance.

In many ways this circuit also acts like the emitter-follower circuit you studied in a previous lesson. The gain is 1, but in this case the amplifier produces inversion which the emitter-follower does not. The low output impedance gives the circuit the ability to provide power amplification.

It is important to note that we can obtain gains less than or greater than 1 because we set the amplifier gain strictly by the ratio of the feedback to input resistors. If we make the input resistance greater than the feedback resistance, the gain will be a fraction. If we put a 2 volt peak-to-peak signal into an amplifier with a gain of .5, the output will be half this, or 1 volt peak-to-peak. The amplifier, with its gain of less than 1, is actually producing a loss. Even though this circuit appears to be ineffective, it is often used in analog computers.

SELF-TEST QUESTIONS

(a) True or false: An op amp is usually a differential amplifier.

(b) True or false: The gain of an op amp circuit is equal to the ratio of the input to feedback resistors. RF : RIN

(c) True or false: An op amp can amplify both ac and dc signals.

(d) True or false: The output signal of an op amp is inverted, or 180° out-of-phase with the input.

(e) True or false: An op amp cannot be connected to provide a gain less than one.

(f) What is the gain of an op amp whose input resistor is 12K and feedback resistor is 84K? 7

(g) An op amp circuit, like that in Fig. 4, has a gain of 4. The input signal is a dc voltage of −3.5. What is the amplitude and polarity of the output?

(h) Name five important characteristics of an op amp.

-16-

1: HIGH OPEN LOOP GAIN
2: HIGH INPUT IMPEDANCE
3: LOW OUTPUT IMPEDANCE
4: WIDE FREQ. RESPONSE
5. DIRECT COUPLING
6: LOW DRIFT
7: LOW POWER CONSUMPTION
8: DIFFERENTIAL INPUTS.

E0 = -GAIN (Ei)
E0 = -4(-3.5
E0 = 14✓

Applications

Early use of op amps was limited primarily to analog computers. Vacuum tube op amps were large, expensive and complex. In order to obtain the accuracies necessary in an analog computer, op amps had to be quite sophisticated. But because of their high cost and complexity, they were not practical for more common electronic applications. However, as transistor op amps were developed, many of the problems associated with the vacuum tube types were eliminated.

For that reason, the op amp has become a practical circuit element. Today it is a common building block, not only in analog computers, but also in many other electronic devices and systems. Design engineers now use op amps as a matter of course in equipment they design.

The op amp is quite versatile in electronic circuits. By varying the types of components in the input and feedback circuits and their particular connections, an extremely wide variety of different operations can be performed. In fact, the op amp is practically unlimited in its application.

In your work you will discover op amps in several major connections. You have already seen the most common op amp connection, where the amplifier provides gain and phase inversion. Now let's examine some other typical op amp connections.

NON-INVERTING OP AMP CIRCUIT

There are times when the phase inversion of the common op amp is not desirable. In such applications we might want a high input impedance, a low output impedance, a particular gain, and no inversion of the signal. This operation can be accomplished by providing the gain in an op amp circuit and compensating for the phase inversion with a unity gain inverter.

Fig. 7 shows how this is done. Suppose we want a gain of 3 with no phase inversion. Amplifier 1 provides the gain of 3. Since this circuit produces phase inversion, we follow it with a unity gain inverter stage to remove the inversion produced by the first amplifier. While this circuit is used in some situations, it wastes parts and power. There is a simpler way to eliminate phase inversion.

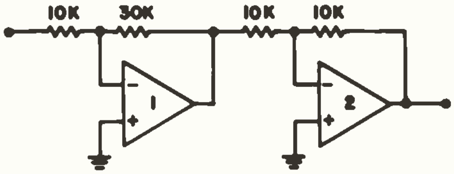
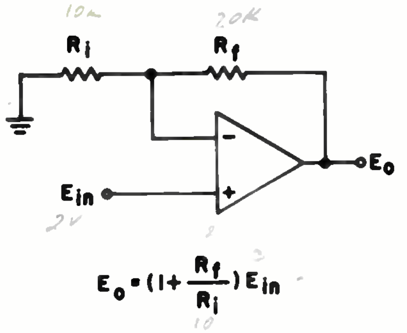


Fig. 7. Using a unity gain inverter to correct for inversion.

In Fig. 8 we show a non-inverting op amp circuit. In this circuit the non-inverting (+) input is not grounded. Instead, we apply the input voltage to this terminal. Input and feedback resistors are connected to the inverting input, but the end of input resistor R_i (normally connected to a signal) is connected to ground. This connection provides a gain that can be adjusted by setting the values of resistors R_f and R_i. The output voltage of this circuit is equal



$$E_0 = \left(1 + \frac{R_f}{R_i}\right) E_{in}$$

Fig. 8. A non-inverting op amp circuit.

to the input voltage multiplied by (1 + R_f/R_i). As you can see the gain is again a function of the ratio of the feedback to input resistances. But because of the particular connections, a value of 1 must be added.

Let's take a typical example and calculate the gain of this non-inverting circuit. Assume feedback resistor R_f is equal to 20K and input resistor R_i is 10K. If we have an input voltage of 2 volts, what will the output voltage be with the gain obtained?

First let's calculate the gain of the circuit: (1 + R_f/R_i) = (1 + 20K/10K) = (1 + 2) = 3. If the input voltage is 2 volts, then the output voltage will be 2 times 3, or 6 volts. Keep in mind that this is a non-inverting circuit. If the input is a sine wave, then the output will be in phase with the input. If the input is a dc voltage, the input and output polarities will be the same.

One of the biggest advantages of this circuit is the high input impedance. With the standard op amp configuration, the input impedance is equal to the value of the input resistor. For some applications this may be very low, causing undesired loading on the driving source. However, in this circuit the input signal is applied directly to the non-inverting input. This input is usually a very high impedance (an infinite impedance for an ideal op amp). Therefore, very little loading of the driving source will occur.

OPERATIONAL AMPLIFIER FOLLOWER

Take a close look at the gain formula for the non-inverting amplifier circuit in Fig. 8. The gain is equal to 1 plus the ratio of the feedback to the input resistances. What would happen if we were to increase the value of resistor R_i in this formula? The ratio of R_f to R_i would decrease. If we made R_i infinite, or disconnected it from the circuit altogether, the gain of this amplifier circuit would be 1. When this condition occurs, we have what is known as an op amp follower.

You already know about cathode and emitter-follower circuits. These are non-inverting buffer circuits whose output is very nearly equal to the input. The non-inverting op amp circuit is easily converted into a follower type circuit. The input resistor is removed and 100% feedback from output to input through resistor R_f is provided to the inverting input terminal. For this type of circuit the feedback resistance can be eliminated and the output connected directly to the inverting input.

The typical follower circuit is shown in Fig. 9. In this circuit the output voltage is equal to the input voltage. The input impedance is extremely high; the output impedance is very low. While the circuit

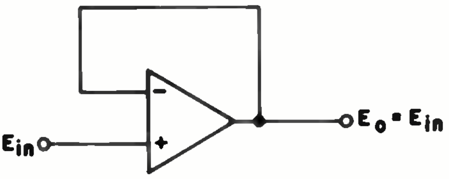


Fig. 9. An op amp follower.

25K

provides no gain or phase inversion, it is useful as an isolation amplifier and a power amplifier.

A particular voltage source may have a high output impedance and, therefore, will be loaded substantially when connected to a load. This may be an undesirable situation, but it can be eliminated with the follower. The high impedance source is connected to the very high input impedance of the op amp follower. Because of this high input impedance, it will not substantially load the voltage source. The output voltage of the op amp is equal to the input. However, its output impedance is very low and can supply substantial current to a load.

A DIFFERENTIAL AMPLIFIER CONNECTION

Since most op amps are differential amplifiers, they have both inverting and non-inverting inputs. In the circuits that we have discussed, however, we have not used this differential input capability. In the standard op amp connection, the non-inverting input is connected to ground. The differential op amp amplifies the voltage difference between the two inputs. If one of these inputs is connected to ground, the difference will simply be the amount of voltage applied to the other input. This forms what is known as a single-ended amplifier input. This means that both the input and output signals are measured with respect to some common ground reference.

There are occasions when it is desirable to use the differential capabilities of the op amp. At the same time, we want to take advantage of the fact that negative feedback around the amplifier can stabilize the circuit and make the gain predictable. The circuit shown in Fig. 10 produces this differential amplifying capability with controlled gain.

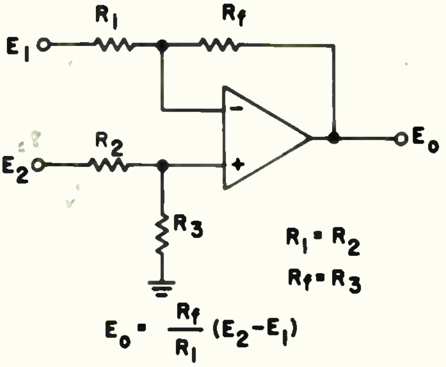


Fig. 10. Using an op amp as a differential amp.

In this circuit the two input resistors are R_1 and R_2. These two resistors are generally made equal. The feedback resistor R_f is connected as usual. Resistor R_3 is connected between the non-inverting input and ground. Resistors R_3 and R_f also are made equal to each other. The gain of the circuit is expressed as R_f/R_1 or R_3/R_2. The output voltage of this circuit is equal to the gain multiplied by the difference of input voltages E_1 and E_2. This gives us the output expression

$$E_o = \frac{R_f}{R_1}(E_2 - E_1)$$

We might also call this circuit a subtraction circuit, since we subtract input voltage E_1 from E_2 in the process of calculating the output.

Let's assume that resistors R_3 and R_f are equal to 100K and R_1 and R_2 are 25K. The gain of the circuit then is 100K/25K = 4. Now let's assume input voltages of $E_1 = 3$ volts, and $E_2 = 8$ volts. The output voltage of the amplifier is the difference between the two input voltages (5) multiplied by the gain of the circuit (4), or 20 volts.

Let's take another example of output voltage calculation of a differential amplifier circuit. Assume that the values of R_f and R_3 are 500K-ohms. Input resistors R_1 and R_2 are also equal to 500K-ohms. Input voltage $E_1 = +13$ volts, and input voltage $E_2 = -2$ volts. What is the output voltage? Using the output formula

$$E_o = \frac{R_f}{R_1}(E_2 - E_1)$$

we get

$$E_o = \frac{500K}{500K}(-2 - 13)$$

$$E_o = 1\,(-15) = -15 \text{ volts}$$

This circuit performs a very accurate algebriac subtraction operation.

AN OP AMP CONSTANT CURRENT SOURCE

In an earlier lesson, you learned how a transistor can be connected to form a constant current source. Now you will find out how an op amp can be connected to perform this same function.

The conventional op amp circuit is shown in Fig. 11. The input is applied to resistor R_i and the gain is determined by the ratio of R_f to R_i. The output voltage is generally applied to a load connected between the amplifier output and ground as shown. Earlier we mentioned that the input and feedback currents were equal. Because of the high input impedance of the op amp, almost no current flows into the inverting input. Therefore the input and feedback currents I_i and I_f in Fig. 11 are equal.

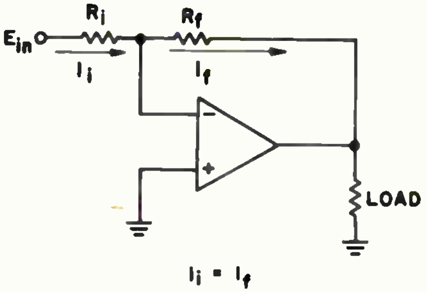


Fig. 11. A conventional op amp circuit with a load showing that the input and feedback currents are equal.

Using this fact, we can produce the constant current source op amp circuit. Fig. 12 shows the arrangement. First we cause a fixed current to flow through input resistor R_i. Since the value of R_i is constant, we can cause the current flow through it to be constant by applying a constant voltage to it. The Zener diode in Fig. 12 is used to provide the constant voltage to resistor R_i.

This fixed current also flows in the feedback resistor. Instead of connecting the load directly between the output of the amplifier and ground, we connect the load as the feedback element. In this way the constant current, determined by the

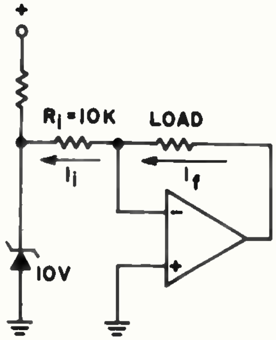


Fig. 12. A constant current source made with an op amp.

Zener diode and the input resistor, also flows through the load. The load resistance can be varied over a wide range of values but the current flowing through it will remain constant. For example, if R_i is a 10K resistor and the Zener diode provides a voltage of 10 volts, then the input current is equal to 10/10K = 1 milliampere. A constant current of 1 milliampere will flow through the load. This current will remain constant despite variations in load resistance.

VARYING THE GAIN OF AN OP AMP

In all the op amp circuits we have discussed, the gain is fixed by the values of the feedback and input resistors in the circuit. However, there are many occasions where we wish to control the gain or vary it continuously over a wide range of values. The most obvious way of varying the gain of any op amp circuit is to replace one of the fixed resistors with a potentiometer connected as a variable resistor.

A potentiometer is nothing more than a variable voltage divider, a resistive network whose output is less than its input by a factor determined by the resistance values used. The "pot" is a variable voltage divider with a continually adjustable resistance ratio.

Fig. 13A shows a typical op amp circuit with a variable resistor at both the input and the feedback positions. However, to control the gain of the amplifier, a variable resistance will usually be required in only one of these positions; a fixed resistor can be used in the other. By varying the input or the feedback resistance, the ratio of the two resistors will change and the gain will vary. Continuous adjustment of the gain is possible with this method.

With this arrangement it is more often desirable to control the gain with a potentiometer in the feedback path than in the input circuit. By varying the potentiometer in the feedback path, we obtain linear control of the gain. If we adjusted the input resistance, the gain would not be linear; it would not vary in a straight line with the value of the resistance. This is because the gain is a function of the ratio of the two resistances.

Also in this arrangement, the input resistance varies as the gain changes, altering the loading of the driving circuit.

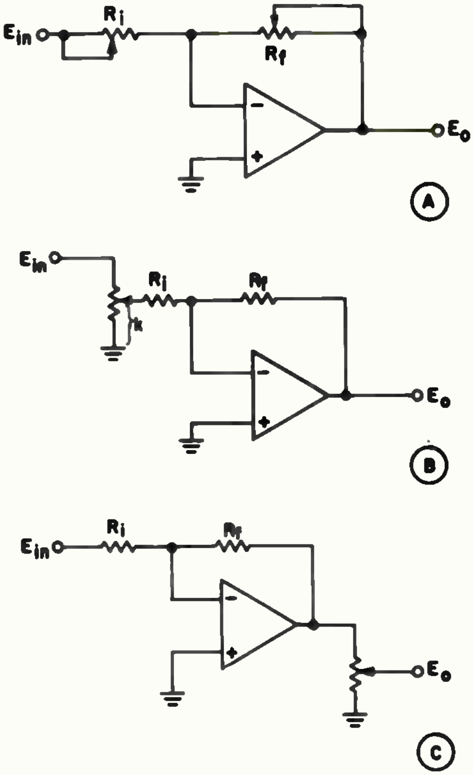


Fig. 13. Methods of varying the gain of an op amp.

The input impedance can even be set to zero, placing a dead short across the source driving the amplifier. In most instances, however, this is not a desirable situation.

An easy method of controlling the gain of an op amp circuit is to place a potentiometer before or after the circuit, as shown in Fig. 13B and C. In both circuits the op amp gain is fixed by the ratio of the feedback and input resistances; the amplitude of either the input or output is controlled with a potentiometer.

Fig. 14 shows a potentiometer connected as a variable voltage divider. The input voltage is applied between the upper end of the potentiometer and ground, causing current to flow through the resistance. The output voltage is taken between ground and the variable arm.

With the arm all the way to the top of the resistance, the output voltage will be equal to the input voltage. If we move the arm to the bottom of the resistance, the output voltage will be zero. Positioning anywhere between the two extremes causes the output voltage to be some fraction of the input voltage. For example, if the input voltage is 100 volts and we set the potentiometer arm to the center of the resistance value, the output voltage will be 50 volts.

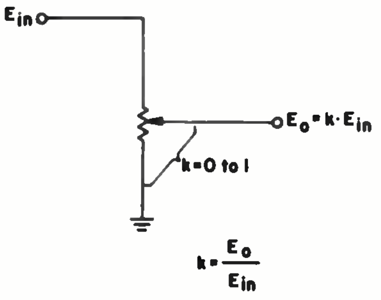


Fig. 14. The input-output relationship of a potentiometer.

In effect we are tapping off a portion of the voltage dropped across the resistance of the pot. Expressed as a fraction, the percentage of voltage tapped off between the arm of the pot and ground is known as the pot coefficient and designated k. In our example, where we assumed a 100 volt input, the coefficient is .5. Multiplying the pot coefficient by the input voltage gives us the output voltage value. With an input voltage of 100 volts and a pot coefficient of .25, the output voltage will be 25 volts. Since the pot is continuously variable, we can set any coefficient between 0 and 1, where the output and input voltages are equal.

Therefore, by connecting the pot at the input or the output of an op amp, we can vary the gain of the amp. The overall gain of the circuit shown in either Fig. 13B or C is equal to the amplifier gain multiplied by the pot coefficient. In other words, the overall circuit gain is equal to

$$\frac{R_f}{R_i}k$$

When the pot is used this way, the overall gain of the circuit can never be more than the total gain of the op amp.

One of the most useful circuits for varying the gain in an op amp is shown in Fig. 15. In this type of circuit, the input and feedback resistors are normally equal. Notice that the feedback resistor is indirectly connected to the output of the op amp through the arm of the pot. With this arrangement the gain of the amplifier circuit is equal to the reciprocal of the pot coefficient. If, for example, the pot

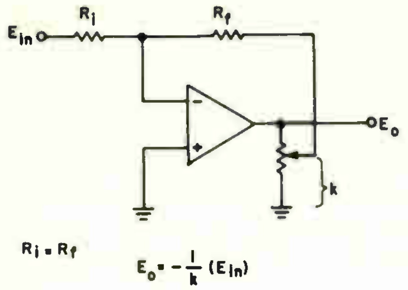


Fig. 15. A variable, high gain, op amp circuit.

coefficient k is .5, the gain of the amplifier is 1/.5 = 2. Since the coefficient of a potentiometer can be adjusted to any value between zero and 1, we can theoretically obtain any gain between 1 and infinity; the only limiting factor is the resolution of the pot setting.

For some potentiometers it is difficult to obtain very small variations in coefficients. We may want to obtain a gain of 1000 with our amplifier, in which case the coefficient would have to be .001. This coefficient is the ratio of 1 to the desired amplifier gain (k = 1/gain = 1/1000 = .001).

The output of voltage from the amplifier circuit, shown in Fig. 15, is equal to the gain of the circuit (1/k) multiplied by the input voltage. Keep in mind that the gain of the amplifier should not be adjusted so high that, with the given input voltage, it causes the output amplifier to swing to an output voltage beyond the power supply voltages used.

SELF-TEST QUESTIONS

(i) The non-inverting amplifier circuit of Fig. 8 has a feedback resistor of 120K and an input resistor of 30K. What is the gain?

(j) The differential amplifier circuit of Fig. 10 has values of $R_f = R_3 = 75K$ and $R_1 = R_2 = 15K$. The input voltages are $E_2 = -23$ and $E_1 = -16$ volts. What is the amplitude and polarity of the output?

(k) True or false: An op amp follower inverts the input signal.

(l) True or false: The load in an op amp constant current source is connected between the output and ground.

(m) A pot has an input voltage of 27 volts and an output of 9 volts. What is the pot coefficient k?

(n) The pot coefficient in the circuit of Fig. 15 is .004. What is the circuit gain?

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Characteristics and Specifications

Most of the characteristics and specifications that we discuss in this section arise from the fact that an op amp is an imperfect device. Like any other electronic circuit, it is made from components that have specific tolerances on their values; undesirable characteristics cannot be completely eliminated in their manufacture.

Despite their imperfection, op amps are still quite useful; their usefulness depends entirely upon their application. By knowing and understanding the characteristics and specifications of op amps, you will be able to compare them and determine whether a particular amplifier is suitable for a given application.

INPUT OFFSET VOLTAGE

Almost all op amps have a differential input stage. As you have seen in previous applications, the two inputs providing inverting and non-inverting operation permit the op amp to be used in a wide variety of circuits. The desirable characteristics of a differential amplifier are taken advantage of in the op amp. As you recall, any differential amplifier amplifies the difference voltage between the two inputs. If we should connect both inputs to ground (0 volts), the difference between the two inputs should be zero; the output voltage would also be zero.

This, however, is only theoretically true. Because of small differences in the characteristics of the transistors used in the input differential amplifier, there will be a small difference of voltage that will be amplified by the high gain of the circuit and appear as a dc output voltage. Therefore, even when both inputs are at ground, there will be a measurable output voltage.

The small difference voltage, that appears in the input differential amplifier when both inputs are connected to ground, is caused by the differences in the emitter-base voltages of the two input transistors. If the emitter-base voltages, designated V_{be}, are exactly equal, there will be no difference between the two input voltages and the output voltage will be zero. When separate transistors are used to form the input differential amplifier, it is very difficult to find two transistors with identical V_{be}'s. For that reason there will be a small difference, appearing as an input signal that is amplified by the high gain of the circuit and appears as a measurable dc voltage at the output. The amount of voltage that must be applied between the input terminals to offset this output voltage is known as the input offset voltage.

★ VIP

In the design of a transistor op amp, the manufacturer normally tries to choose matched input transistors. Special test set-ups are used to compare the emitter-base voltages for the input transistors to match them as closely as possible. This reduces the input offset voltage. Some manufacturers produce special differential transistors with an extremely small difference voltage. Integrated circuit op amps, which you will study later, are very good in this respect. The transistors of the input amplifier are constructed on the same chip of silicon material and exhibit almost identical characteristics, reducing this input offset voltage to practically zero.

In a good op amp, this input offset voltage varies anywhere from several hundred microvolts to about 10-20 millivolts. When you consider the fact that the open-loop gain of an op amp is many thousands, this voltage can be amplified to a substantial signal at the output. For this reason we must generally take steps to correct this condition.

Fig. 16 shows a circuit that can be used to compensate for input offset voltage. This circuit is a standard inverting op amp circuit with feedback and input resistors. When we ground the input resistor as shown, the output voltage should be zero. In a practical circuit the output will not be zero, however, due to the input offset. If, for example, R_f = 100K and R_i = 100 ohms, the circuit gain would be 100K/100 = 1000. With an input offset voltage of 5 millivolts, the output would be .005 X 1000, or 5 volts. This is far from zero as you can see.

To compensate for this, we can apply a correction voltage from a potentiometer, as shown. The pot is connected to both plus and minus power supply voltages. This enables us to apply either a negative or a positive voltage to resistor R_1 which feeds the offset voltage into the op amp.

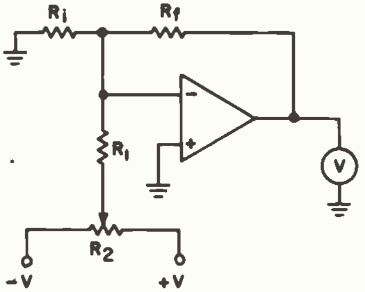


Fig. 16. Correction for input offset voltage.

Since we do not know in which direction the offset voltage will force the output, we can apply the desired correction voltage by making the input voltage polarity and the amplitude variable with the pot. With the input resistance R_i grounded and a voltmeter connected to the output, potentiometer R_2 is adjusted until the output voltage is equal to zero. The input offset voltage is then corrected.

The input offset voltage limits the magnitude of the input signal that the amplifier can amplify. For example, if the input offset voltage were 5 millivolts, we could not handle or amplify dc signals of 2 millivolts amplitude. Such small level signals, approximately the same magnitude of the offset voltage, will be confused with the offset voltage. An unpredictable output can result. However, by balancing out the offset voltage with a circuit like that in Fig. 16, we can then handle small amplitude signals. In noncritical applications where very low gain is used and where the signal voltages are many times larger than the offset, it is often possible to disregard the need for input offset voltage correction if a good op amp is used.

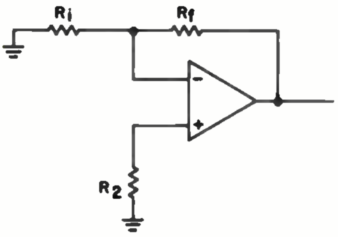
INPUT OFFSET CURRENT

The input offset current is the difference between the two input currents with both of the op amp inputs connected to ground. This difference in base currents is amplified and the result is an output voltage. The average of the two input base currents is called the input bias current. It is found by adding the input currents and dividing the sum by two.

This offset current is a function of the balance, or matching, of the input transistors in the differential input stage. Instead of being the result of differences in V_{be}, as with input offset voltage, the input offset current is a function of the degree of matching between the Betas and leakage currents of the input transistors. Because the two transistors used in the differential stage will not have equal Betas or collector-base leakage currents, different amounts of base current will flow when the inputs are connected to ground. This difference between the two currents (the input offset current) is amplified and produces an offset output voltage.

This current can be compensated for in the same way we correct for offset voltage (Fig. 16). Because of the directions of the current and possible opposite voltage offsets, it may be necessary to apply correction input to both the inverting and non-inverting inputs in order to compensate for both effects. Normally, however, the arrangement shown in Fig. 16 will enable you to null out the effect of input offset voltages and currents.

Fig. 17 shows an op amp circuit that can be used to help minimize the input offset current effects. Instead of connecting the non-inverting input directly to ground, as in previous circuits, we insert a resistor between this input and ground. By making this resistance equal to the parallel combination of the normal input and feedback resistances, the input currents can be made very nearly equal so that their results will cancel. The result will be a minimum of output voltage offset due to this input offset current. By making R_2 in Fig. 17 fully adjustable, it is possible to bring the offset to practically zero. If the input and feedback resistors are both 100K, the parallel combination will be equal to one-half this value. R_2 in the circuit would be made 50K for minimum offset current effects.



$$R_2 = \frac{R_f R_i}{R_f + R_i}$$

Fig. 17. Input offset current compensation.

INPUT IMPEDANCE

One of the most important characteristics of an op amp is the input impedance, the resistance at the input of the amplifier. In other words, each differential input represents a certain amount of resistance to ground to some driving source. It is desirable to have this input impedance as high as possible so that the circuit does not load or draw current from the source driving it.

Whenever this input resistance is connected to an oscillator, amplifier or other voltage source, current will flow through the input impedance and effectively load the driving source. If the input impedance is too low, excessive loading of the driving source may occur and result in reduced input voltage. Therefore the higher the input impedance, the lower the current drawn from the source.

Most typical op amps with no feedback connections have an input impedance of from 20K to 500K-ohms. This is the impedance of a typical bipolar transistor op amp. Higher input impedances can be obtained with Darlington input differential amplifiers. When field effect transistors are used for the input differential amplifier, extremely high values of input impedance (even thousands of megohms) are possible.

There is one special technique used with op amps to increase the input impedance. Known as bootstrapping, this technique involves taking some of the output voltage of the same polarity as the input voltage and feeding it back to the input. This compensates for the amount of current being drawn by that input from the source. In other words, we supply a current of proper polarity from the output of the amplifier to the input to furnish the current to the input normally drawn from the source. By effectively canceling out the current drawn from the source, the apparent input impedance becomes infinite.

The circuit shown in Fig. 18 uses this bootstrapping technique. Notice that resistors R_1, R_2, R_3 and R_4 have been added to form a voltage divider which taps off part of the output voltage which is fed back to offset the need for input current from the signal source.

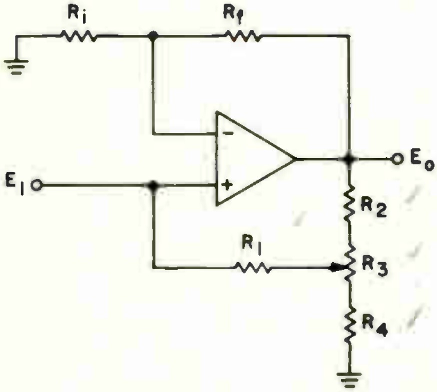


Fig. 18. A non-inverting op amp with bootstrapping to increase input impedance.

OUTPUT IMPEDANCE

The output impedance is the value of the effective internal resistance of the amplifier when it is acting as a voltage generator. The output of an op amp appears to be a source of voltage for whatever load it drives. The output impedance of the op amp appears in series with this load. Ideally we would like to have a very low output impedance so that little or none of the voltage produced is dropped across the internal impedance of the amplifier; almost all of it should appear across the load.

The output impedance of a typical transistor op amp without feedback is generally several hundred ohms. However, this value is reduced substantially when feedback is used. By using negative feedback, as we normally do with an op amp, output impedances of less than 1 ohm are easily obtainable. If the gain of the amplifier is very high, output impedances of .01 ohm are not too difficult to obtain.

POWER CONSUMPTION

Power consumption is the dc power required to operate the amplifier with the input and output voltages at zero and no load current flowing. This is the quiescent amount of current drawn by the amplifier when no input signal is applied or output is being developed.

Remembering that power is equal to the product of the voltage and the current, you can easily find the power consumed by an op amp. Most op amps use two power supplies, one to supply a negative voltage and the other a positive voltage. For example, a typical op amp may require + and − 15 volt power supplies. If the current drawn from each of these 15-volt power supplies is 2 milliamperes, power consumption would be 30 volts × .002 ampere = .06 watt, or 60 milliwatts.

INPUT VOLTAGE RANGE

The input voltage range is a measure of the maximum amount of voltage that can be applied between the two inputs of the op amp. If this value is exceeded, damage may occur to the input differential amplifier transistors. Normally this voltage range is restricted by the reverse emitter-base breakdown voltage of the input transistors.

OUTPUT VOLTAGE SWING

The output voltage swing is the peak or maximum output voltage, with reference to zero, that can occur without clipping or other distortion. This voltage swing is generally limited by the power supply voltages. For example, in an op amp with power supplies of ±15 volts, the maximum output voltage swing would be very nearly equal to 30 volts. For an ac sine wave at the output, this would be a 30-volt peak-to-peak value. Normally, the maximum output voltage swing is less than the supply voltage by an amount equal to the drop across the saturated output transistor and any series resistance.

When the input voltage is low enough so that, when it is amplified by gain of the amplifier it produces an output voltage within the output voltage swing, the amplifier is said to be operating in the linear region. That is to say, the output voltage is an enlarged copy of the input voltage. The amplifier does not distort the signal.

However, if the input voltage is made too large, the gain of the amplifier may be such that we exceed output voltage swing capabilities of the amplifier. In this case, the amplifier output will saturate. If the input signal is a sine wave, both the positive and negative peaks of the output will be clipped because the output transistors go into saturation. To avoid going beyond the output voltage swing capability, always check to be sure that the output voltage is less than the maximum value when you multiply the input voltage by the gain of the amplifier.

COMMON MODE REJECTION

The inputs to an op amp are the inputs to a differential stage. As you recall from your study of differential amplifiers, it is the voltage difference between the two inputs that is amplified by the stage and fed to the output. This means that if both input signals are equal, the output voltage should be zero.

The ability of the amplifier to produce a very small or zero output voltage for equal input voltages is known as the common mode rejection. The ratio of the common mode input voltage to the output voltage produced is known as the common mode rejection ratio. For example, if we apply 10 volts to both inputs of the amplifier and the resulting output voltage is 1 millivolt, the common mode rejection ratio is 10/.001 = 10,000.

Normally the common mode rejection ratio is specified in decibels. The common mode rejection ratio that we just calculated, expressed in decibels, would be equal to 20 log 10,000 = 20 × 4 = 80 db. The larger the common mode rejection ratio figure, the better the rejection ratio and the quality of the amplifier. Common mode rejection ratios of well over 100 db are not uncommon in op amps.

POWER SUPPLY REGULATION

The input offset voltage of an op amp is sensitive to changes in the power supply voltages. We call this op amp characteristic the power supply rejection ratio. This is basically the ratio of the change in input offset voltage to the change in the supply voltage producing it. Normally, the op amp has two power supplies, one held constant and the other varied in voltage. Therefore, any input offset voltage change is noticeable. The ratio of the input offset voltage change to the supply voltage that caused it is the power supply sensitivity.

The power supply sensitivity is a function of the balance or matching in the input differential amplifier. If the differential amplifier transistors are as closely matched as other components in the circuit, the change in input offset voltage for a power supply voltage change will be very small. The quality of the amplifier is inversely related to this variation.

OPEN-LOOP DC VOLTAGE GAIN

The voltage gain of the op amp without external feedback is called the open-loop dc voltage gain. As we mentioned before, the open-loop gain of an op amp is generally very large. Gains of 100,000 or more are not uncommon. However, most op amps will use some form of negative feedback to reduce the amplifier gain and make it more predictable.

As you saw earlier, negative feedback through a resistance between the output and the inverting input makes the gain strictly a function of the ratio of the feedback to an input resistance. It is very desirable to be able to control the gain in this way. In order for this relationship to hold true, however, the open-loop gain of the amplifier should be at least 100 times the desired closed-loop gain of the amplifier.

NOISE

All amplifiers are sensitive to and produce a certain amount of noise. Noise is a term that describes any stray signal voltage (produced within the amplifier or external to it) that is amplified and appears in the output. Noise is an unwanted signal, generally measured in terms of rms voltage, that may interfere with the amplification of a specific input. If the noise level of the amplifier is higher than the small signal to be amplified, the input signal will be completely masked; only an amplified noise output will occur. Therefore, it is important that the noise in the amplifier be minimized.

There are several types of noise which can occur in op amps. We generally break these down into noise components associated with specific frequency ranges. One of these, called the wide band noise spectrum, extends from about 1 kHz to 100 kHz. Noise produced in this frequency range is generally from thermal effects in resistors and from within semiconductor components, such as diodes and resistors. This type of noise is internally generated.

Another noise spectrum extends from the frequencies of 10 Hz to 1 kHz. Noise in this region is usually from the ac power line and frequencies harmonically related to it.

In the frequency range from 1 Hz to 10 Hz, noise is caused by structural imperfections in the components (particularly transistors) and is known as flicker noise.

In the frequencies above 100 kHz we move into the radio frequency spectrum, and amplifiers can pick up rf signals. Of course, this is undesirable. It is best to minimize the amount of noise produced both within the amplifier and external to it. This is particularly true if extremely low level signals are to be amplified properly.

DRIFT

Drift is a form of very low-frequency noise; it is the slowly varying change in the input offset voltages and currents in an op amp due to fluctuation in temperature, time and power supply voltages. We want to minimize drift in the design and application of the amplifier because variations in offset voltages and currents are amplified and interfere with the normal input signal.

No relationship exists between the input offset voltage drift and input offset current drift. As temperature, time or power supply voltages change, each of these factors will vary independently, often in opposite polarity to the other. Since drift is an undesirable characteristic of the op amp, every means must be taken to minimize or eliminate it. Let's now discuss the causes of drift and how it can be minimized.

A major cause for drift is temperature change. Electronic equipment using op amps can be subjected to a wide range of temperatures. Temperature effects can come from the environment or from heat in adjacent electronic components or equipment. Such temperature effects must be considered when designing and using an op amp.

Most operational amplifiers and components are available in two basic temperature ranges, the commercial range from 0°C to 70°C and the military temperature range of –55°C to +125°C. These are the typical temperature ranges over which the op amp must work for these specified applications. Since the temperature ranges are so wide, care must be taken to protect the amplifier.

Temperature variations cause changes in the input offset voltage and current which can produce undesirable amplifier action. As the temperature varies, the emitter-base voltage drops of the differential input transistors vary. Normally the emitter-base voltage drop decreases 2 millivolts for every °C increase in temperature. If the two differential input transistors are accurately matched, their emitter-base voltage drops will decrease together as temperature increases, maintaining a balance and keeping the input offset voltage reduced to a minimum.

Recall that the input offset voltage is due to the differences between the emitter-base voltage drops in the input differential amplifier. It is extremely difficult to control the manufacture of these transistors so that the emitter-base voltage drops track together with temperature. For that reason the input offset voltage will change when the temperature changes. Emitter-base junction voltages are so sensitive to temperature changes that a temperature difference of only .01°C between the junctions of two transistors in the input stage can produce an input offset voltage of 24 microvolts.

As you can see, it is important to hold the junction temperature of the two transistors to exactly the same value. Keeping the input offset voltage low, when individual transistors are used in the differential stage, is quite difficult. Generally the transistors can be mounted on a common heat sink. Also there are special differential transistor pairs manufactured, where both are made from the same silicon chip. Often special heating elements or ovens are used on the differential input stage to keep the temperature at a constant value to reduce the changes in the offset voltage that produce undesirable drift.

Drift due to changes in input offset voltage is generally specified in millivolts per °C of temperature change. For example, a typical drift may be .05 millivolt per °C. This can be evaluated by varying the temperature, noting the input offset voltage drift and then calculating the change for a given increment of temperature.

Fig. 19 shows a curve relating the change in input offset voltage to a change in temperature. At 25°C (room temperature), the input offset voltage is nulled to zero. Normally this is done by using the compensation circuit shown in Fig. 16. As the temperature is lowered, the offset voltage increases in the negative direction. Raising the temperature from 25°C causes an increased offset voltage in the positive direction. As you can see, the input offset compensation voltage applied by the circuit in Fig. 16 is effective only at one temperature; the output will drift due to the change in offset voltage at other temperatures.

Notice in this curve that the offset voltage does not change linearly with temperature. In other words, equal temperature change does not produce a proportional change in input offset voltage. In addition, the offset voltage in one amplifier varies independently from that in another.

The input offset voltage also tends to drift with time. That is, the input offset voltage will change over a long period of time. Normally this condition is expressed in microvolts of offset change per days or per thousand hours. This change is generally caused by the physical changes inside transistors because of their age. In most op amps, this characteristic is not particularly detrimental to the operation of the circuit. Only in the most

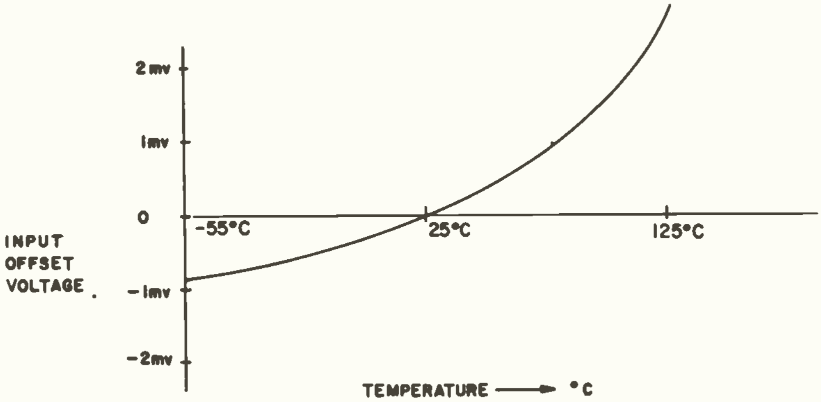


Fig. 19. Input offset voltage vs. temperature.

critical applications is the offset change with time a crucial factor.

The input offset current in an op amp also drifts with temperature and time changes. As you recall from our earlier discussion, the input offset current is a function of both the gain, or Betas, of the input transistors and the leakage currents. Both these factors increase when temperature rises. In silicon transistors leakage current generally doubles for every 10°C increase. If the input transistors are matched so that their Betas and leakage currents vary the same amount with changes in temperature or age, then the offset current will not change. However, it is extremely difficult to match the input transistors this closely; they will change differently with temperature, increasing the amount of input offset current with an increase or decrease in temperature.

Changes in Beta or leakage with temperature do not directly correspond to changes in input offset voltage. In one particular situation, they may vary together and their effects may add; in another case their effects may oppose one another. It depends upon the individual components and the circuit in which they are used.

Generally the same precautions used to minimize input offset voltage changes with temperature can be used in minimizing changes in input offset current. Mounting the transistors together on a common heat sink or using differential transistor pairs made on the same silicon chip will help eliminate the effects of temperature changes.

As with input offset voltage changes, the offset current will vary due to aging of the transistors. There is very little that can be done except to try to match the transistors for aging effects as closely as possible. These are usually long term, very slow drift effects which can be neglected for most applications.

FREQUENCY RESPONSE

As you learned in an earlier lesson on amplifiers, amplifier circuits generally respond to a specific band of frequencies. Amplifiers are classified according to the frequency range in which they amplify best. There are audio amplifiers, video amplifiers, rf amplifiers and dc amplifiers. The op amp is a special case in that it covers a wide range of frequencies. This wide frequency response capability adds to the versatility of the op amp.

We defined frequency response in terms of bandwidth. Bandwidth, as you recall, is the difference between the upper and lower three db cutoff points on the amplifier response curve. For op amps the lower frequency limit is dc. The upper 3 db point primarily depends upon the internal capacitances of the op amp circuit and components as well as external capacitance, inductance and other stray impedances. Op amps have been constructed to perform at frequencies up to 100 MHz.

Now let's take a look at a typical frequency response curve for an op amp. In Fig. 20 the upper curve shows the frequency response of the op amp operating with no feedback. The curve is designated as A_1. This is the open loop response that indicates how the gain of the amplifier varies with frequency. Notice that the gain remains constant for only a very narrow frequency range before it begins to decrease linearly as the frequency is increased. The 3 db down point for the open-loop gain occurs at an extremely low frequency, f_1, that is about 100 Hz or less. Beyond this point

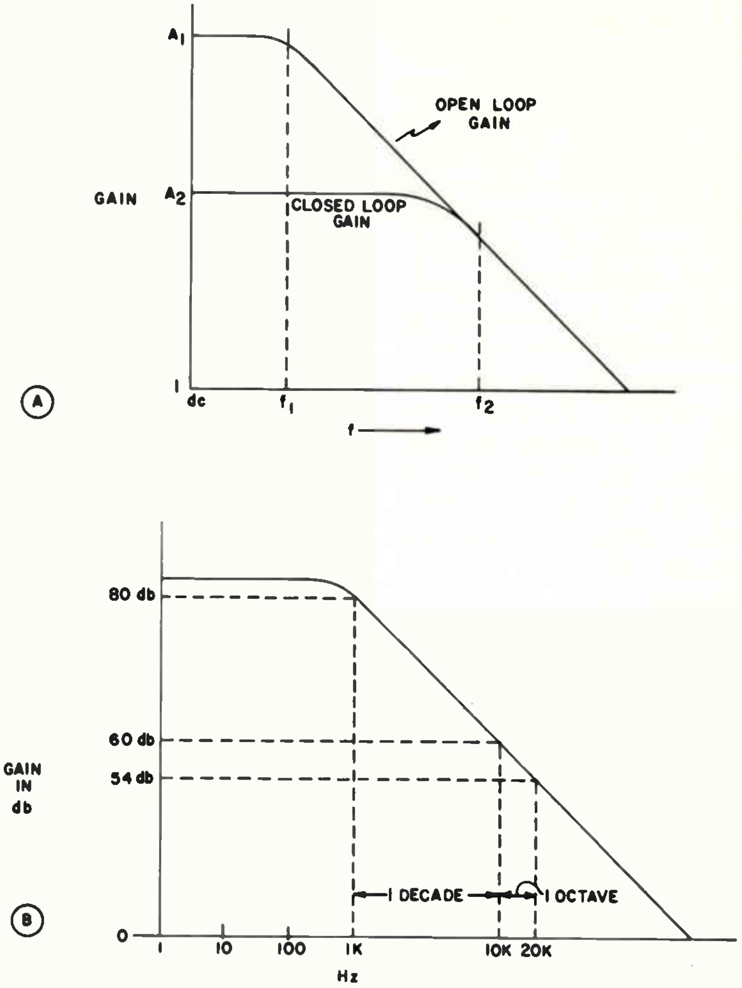


Fig. 20. Op amp frequency response (A) and an op amp frequency response curve that illustrates the roll-off characteristic (B).

the gain decreases in a straight line as the frequency increases until the gain is equal to one (unity).

The lower curve shown in Fig. 20A is the closed-loop frequency response of the op amp. If we apply negative feedback to the op amp, we immediately reduce its gain. At the same time we also increase its bandwidth. Notice that the 3 db down point (f_2) for the closed-loop gain response is far greater than that of the open loop gain response. Here we are trading off gain for frequency response by adding the negative feedback. Notice that the initial gain is lower, but that beyond the 3 db point, the closed-loop gain response merges with that of the open loop gain response and the gain drops linearly as the frequency increases.

The rate of decrease in gain with respect to frequency is generally called the roll-off. The gain roll-off characteristics of an op amp are generally set so that the gain decreases at a rate of 6 db per octave. This means that the voltage gain drops by a factor of 2 each time the frequency doubles. Expressing this another way we can say that the gain roll-off occurs at a rate of 20 db per decade; when the frequency is increased by a factor of ten, the gain is decreased by a factor of ten.

Fig. 20B illustrates this gain roll-off characteristic. The gain in this curve is expressed in db and the frequency in Hz. If the frequency should increase from 1 kHz to 10 kHz, we can say that the frequency increased by a decade or by a factor of ten. The gain of the amplifier at 1 kHz is 80 db, and it drops to 60 db at the 10 kHz point. 80 db represents a gain of 10,000 while 60 db represents a gain of 1,000. Therefore, as the frequency increased by a factor of ten, the gain dropped by a factor of ten.

Notice on this same curve that as we increase the frequency from 10 kHz to 20 kHz the gain drops a small amount. We have effectively doubled the frequency which represents one octave. The gain has dropped 6 db, representing a factor of 2. (60 db represents a gain of 1,000 while 54 db represents a gain of 500.)

There is one specification of an op amp that helps define the relationship between gain and frequency. Known as the gain-bandwidth product, this term will show you the general relationship between the gain of the amplifier and its bandwidth when negative feedback is applied.

The gain-bandwidth product of an amplifier is a constant which is determined by the amplifier design. This means that as we change the gain of the amplifier, the bandwidth must also change in order to keep the product of the two constant. For example, an amplifier with a gain-bandwidth product of 10^6 would have a bandwidth of 10^6 Hz at unity gain. Multiplying the gain of one by the bandwidth of 10^6 Hz we get 10^6 gain-bandwidth product. Now assume that we increase the gain of the amplifier to 100. As you would expect from looking at the curve of Fig. 20B, increasing the gain would have the effect of decreasing the bandwidth. With a gain-bandwidth product of 10^6 and a gain of 100, the bandwidth must be $10^6/100 = 10^4$ Hz or 10 kHz.

SLEWING RATE

The slew rate limit of an op amp is the maximum time rate of change of the output voltage for a step input voltage. This is sometimes known as the velocity limit. The slewing rate is usually specified in terms of the change in output voltage per unit of time; volts per microsecond is typical. It is closely related to the frequency response of an amplifier.

In a previous lesson you studied the square wave testing of amplifiers where a step voltage or square wave was applied to the input and the output of the amplifier then noted. The change in shape of the square wave by the amplifier gives much useful information about the response characteristics of the amplifier. A step response signal (square wave) contains a large number of high-frequency harmonic sine waves. If the amplifier passes these high-frequency harmonics faithfully, the output waveform should be the same as the input waveform. However, since some of the high-frequency components will be attenuated by the limited bandwidth of the amplifier, the output waveform will actually be different from the input waveform. The amount of difference determines the bandwidth of the amplifier. This can be calculated by measuring the output rise time of the square wave of the amplifier.

Fig. 21 shows a step voltage input applied to an op amp. Notice that the rise time for the pulse is zero. In a practical situation, the rise time of the input pulse would be finite. It is usually made so much smaller than the expected output rise time that its effects can be eliminated.

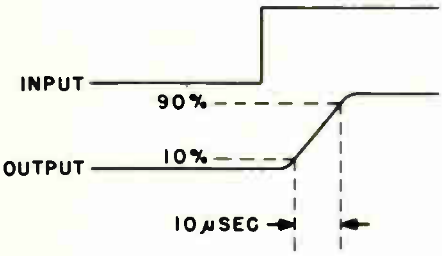


Fig. 21. The step response of an op amp.

The output of the op amp is also shown in Fig. 21. Notice that the output has a very definitely measurable output rise time. These waveforms might be displayed on an oscilloscope and the calibrated horizontal sweep and crt screen will be used to measure the rise time between the 10% and 90% points of the waveform.

Frequency Compensation. Because of the very high gain and frequency response characteristics of an op amp, the circuits are often susceptible to instability when feedback is used. Instability refers to the tendency of an amplifier to oscillate. Naturally any oscillation in an amplifier is undesirable. In op amps oscillation can be eliminated by using frequency compensation techniques.

As you know, the gain of an amplifier varies with the frequency. When feedback is used, the gain is relatively constant over a range of frequencies. Then as the frequency approaches an upper limit, the gain begins to roll off at a constant rate.

As you recall from your previous studies of amplifiers, as frequency increases the gain drops off and substantial phase shift is introduced. At the half power (3 db down) point the phase shift between the input and output signals will be 45°. This phase shift will increase further as the frequency is increased and the gain continues to roll off. It is possible that at some point during the roll-off the phase shift will equal 180°. Combining this with the 180° phase shift or inversion of the op amp and assuming a feedback connection, the output signal will effectively be in phase with the input. If the gain is equal to or greater than 1 at the point where the 180° phase shift occurs, then the amplifier will oscillate. The frequency of oscillation will be the frequency at which the phase shift is proper for in-phase feedback.

To avoid this unstable condition at high frequencies, it is often necessary to connect external resistor-capacitor networks to an op amp to shape the output response curve. This makes the gain roll off at a rate where the phase shift will not be 180° when the gain of the amplifier is equal to or greater than unity.

The phase shift characteristics of an amplifier depend upon the amplifier circuit and the various external resistor-capacitor networks used. Occasionally at high frequencies, these characteristics cause the phase shift to approach 180° when the amplifier gain is equal to or greater than one. Even without feedback an amplifier can oscillate in the open-loop condition. This is due to stray capacities and coupling between circuits of the amplifier caused by the common power supply impedance.

Such instabilities can be eliminated by using an external frequency compensation network that forces the amplifier to roll off at a 6 db per octave rate. Doing this makes the amplifier appear to have the frequency response of a simple R-C integrator network. Such a network has a maximum phase shift of 90°. Since the amplifier can never achieve the 180° phase shift, it will be stable over its useful frequency range.

SELF-TEST QUESTIONS

(o) What is the basic cause of input offset voltage?

(p) What causes input offset current?

(q) Why is a high input impedance desirable?

(r) What is meant by rise time?

(s) What determines the maximum output voltage swing of an op amp?

(t) What causes drift in an op amp?

(u) Does the circuit of Fig. 16 compensate for the effects of drift?

(v) A certain op amp has a gain of 120 db at 100 Hz. What is its gain at 1 kHz if the gain rolls off at 6 db per octave?

(w) Why are external frequency compensation networks often used with op amps?

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Typical Circuit Techniques

Fig. 22 is a generalized block diagram of an op amp, showing its three stages. The first stage is called the input stage. It is always a differential amplifier. Usually a current source feeds the emitters of the differential transistors. This current source is either a single high value resistor or a transistor, forming an active current source. This stage is important because it determines the input characteristics of the op amp. The input offset voltage, input impedance and common mode rejection, for example, are primarily determined by how the input stage is designed.

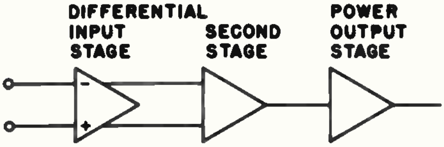


Fig. 22. An op amp block diagram.

Since op amps are dc amplifiers, the first stage is directly coupled to the second stage. The second stage provides more amplification and produces the proper level translation for the dc signals on which the ac input signals are riding. Without level translation there is a buildup in the dc voltage coupled from stage to stage. Also the output will not swing near ground so that the output is zero when the input is equal to zero volts. We could have shown the second stage in Fig. 22 as two blocks, one showing a gain stage and the other a level translator or shifter.

In many op amps there are more than two stages of gain. Usually the differential signal is eliminated after the second or third stage and only a single-ended output is fed to some form of power output stage.

The power output stage has two functions. First it tends to maximize the output voltage the amplifier can handle. (A large output voltage is a desirable op amp characteristic.) It also determines the output impedance (which must be as low as possible) and the current handling capabilities of the amplifier. In many cases the output stage must also provide some form of short circuit protection.

BASIC CIRCUITS

Let's now discuss in detail some amplifier circuits which illustrate how the blocks in Fig. 22 are filled. Fig. 23 is the circuit of a simple but complete op amp which illustrates most of the principles involved. In this circuit the first stage is made up of transistors Q_1 and Q_2, which form a differential amplifier. The input to transistor Q_1 is an inverting input, while the input to transistor Q_2 is the non-inverting input. The emitter of both stages of the transistors of the differential amplifier must be fed by some form of current source. In this case, a very simple current source is made by having a large value resistance (R_4) connected to minus supply $-V_{ee}$. Resistors R_1 and R_2 are the load resistors for the first stage transistor.

The collectors of transistors Q_1 and Q_2 are direct-coupled to the bases of transistors Q_3 and Q_4, which form the second stage. The second stage emitters are also fed by a current source, in this case

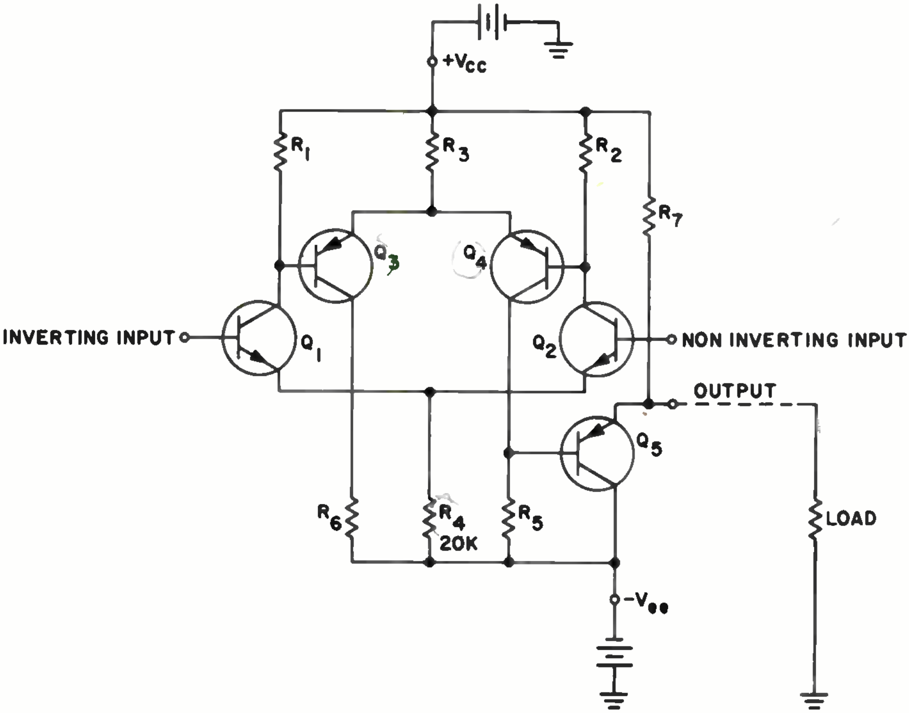


Fig. 23. A simple operational amplifier.

formed by a voltage $+V_{cc}$ and resistor R_3.

In this simple amplifier, NPN transistors are used for the first stage and PNP's are used for the second stage. The use of PNP transistors in the second stage automatically gives us the ability to level-shift the voltage. Remember that the voltage builds up only if we use transistors of the same polarity.

The collector voltages of the second stage are shifted to a level very near ground. The output of the second stage comes from the collectors of transistors Q_3 and Q_4. However, the output from the collector of transistor Q_3 is not used; it is simply returned through resistor R_6 to $-V_{ee}$. Meanwhile the output of transistor Q_4 goes to load resistor R_5 which is coupled to output transistor Q_5. As you can see from the diagram, the output stage in this op amp is made up of transistor Q_5 connected as an emitter-follower.

This amplifier, having most of the desired characteristics of an op amp, is suitable for general purposes. The transistors of the first stage must be matched very carefully in order to obtain a low input offset voltage and current.

To get an idea of the level of performance of this simple circuit, let's outline its characteristics: input impedance, 100K; input current, 600 nanoamps; equivalent input offset voltage, 1 millivolt; voltage gain, 73 decibels. This amplifier uses a simple differential amplifier for an input stage. However, in many cases a more sophisticated input stage design is required to increase the input impedance, increase the common mode rejection ratio or obtain lower values of input bias current.

The high input impedance and the low bias current are direct results of each other. To achieve a high value of common mode rejection ratio in both cases, an active current source is used to feed the emitters. The active current source is usually made up of a transistor and some resistors.

HIGH INPUT IMPEDANCE

In order to obtain a high input impedance, three methods are commonly used: ① Darlington connected transistors in the ② differential input stage, a field effect transistor differential amplifier input stage and ③ a standard transistor connection. We will now discuss these three approaches and the active current sources.

In Fig. 24 is an input stage using both a Darlington connected differential amplifier stage and an active current source. The current source is formed by transistor Q_5; resistors R_1, R_2 and R_3; and diode D_1. The purpose of the current source is to produce a constant current feeding the two emitters of the differential Darlington pair. This current should be stable enough not to change with temperature or bias conditions. Resistors R_1 and R_2 form a voltage divider taken from the power supply. The

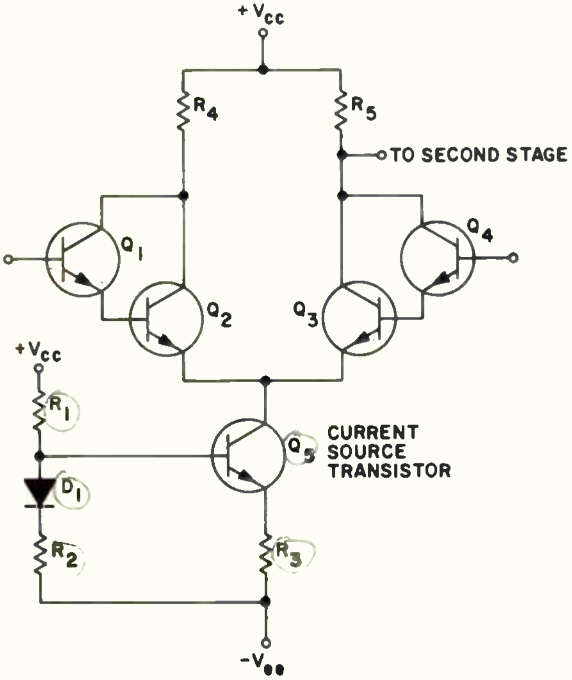


Fig. 24. A Darlington stage and an active current source.

voltage at the base of Q_5 is determined by this voltage divider. This means that the voltage drop across R_3 will also be determined by this divider, since the base potential and emitter potential will be the same. This now establishes a constant voltage across R_3 which implies a constant emitter current (emitter current = emitter voltage/R_3). The collector current is the emitter current multiplied by the alpha of the transistor. The output at the collector is a very high impedance, which simulates an ideal current source.

The use of a transistor as a current source gives us much better current stability than a high value resistor connected to the power supply. Diode D_1 is used in order to achieve a certain degree of temperature compensation. As you know, the emitter-base junction of a transistor has a negative temperature coefficient. That is, V_{be} decreases with an increase in temperature. Diode D_1 tends to cancel out the variation in temperature of the emitter-base junction by introducing an equal voltage with a polarity that cancels the effect. In this way, we obtain a more stable current with regard to temperature changes. For example, if the temperature increases, V_{be} will decrease, causing more voltage to appear across R_3 and increasing the current in Q_5. However, the drop across D_1 decreases, reducing the voltage applied to the base of Q_5 and the voltage appearing across R_3. Therefore, the current remains constant. We must be careful to match the two temperature coefficients of the emitter-base junction of the current source transistor with the one of diode D_1.

The differential amplifier stage in Fig. 24 is made up of Darlington pairs Q_1 and Q_2 on one side and Q_3 and Q_4 on the other. The effect is to achieve a much higher value of Beta. Therefore, for a certain emitter current, the amount of base current that flows into the input transistors will be much less than with a single transistor. This, of course, achieves a small value of input current and a much higher input impedance.

The use of the Darlington connection for the input stage of an op amp is limited because of the input offset voltage and the input offset temperature coefficient. The reason is that the input offset voltage is the net difference in V_{be} drops from one input to the other. Since we now have four transistors, it is more difficult to obtain a low value of input offset voltage. Also the V_{be} of the four transistors must be very closely matched for temperature coefficients, more so than if we had a standard differential pair.

In the input stage shown in Fig. 24, resistors R_4 and R_5 are the load resistors. The output from R_5 is used to drive a second single-ended stage. We could go to a differential second stage with PNP transistors as we did before, then convert to a single-ended output after the second stage.

Another method of obtaining a high input impedance is to use a standard differential amplifier stage, operate the transistors at a very low value of collector current and manufacture the transistors so that their Betas are extremely high at these low values of collector current. This is sometimes referred to as the super-Beta technique. It is very difficult to make transistors that have a very high Beta at low values of collector current. In order to get a high Beta, we must make the base of the transistors so thin that the reverse breakdown characteristics are severely restricted. Therefore, we must sacrifice the magnitude of our input voltage to low values in order to get the higher gain.

The use of field effect transistors to obtain high input impedance is shown in the complete op amp diagram of Fig. 25. This op amp offers a much higher performance than the first one we discussed. Transistor Q_5 forms the active current source that we discussed in the previous section. Diode D_1, the 3.3K resistor and the 224K resistor form the voltage divider used to establish the emitter voltage reference. As before, D_1 is used for emitter current stabilization with temperature. The collector of Q_5 is connected to the emitters of Q_2 and Q_4 and through 3K stabilizing resistors to the sources of field effect transistors Q_1 and Q_3. The two input signals are applied to the gates of transistors Q_1 and Q_3 which are N-channel field effect transistors. The sources of Q_1 and Q_3 are connected to the bases of Q_2 and Q_4, directly coupled.

As you know from previous lessons,

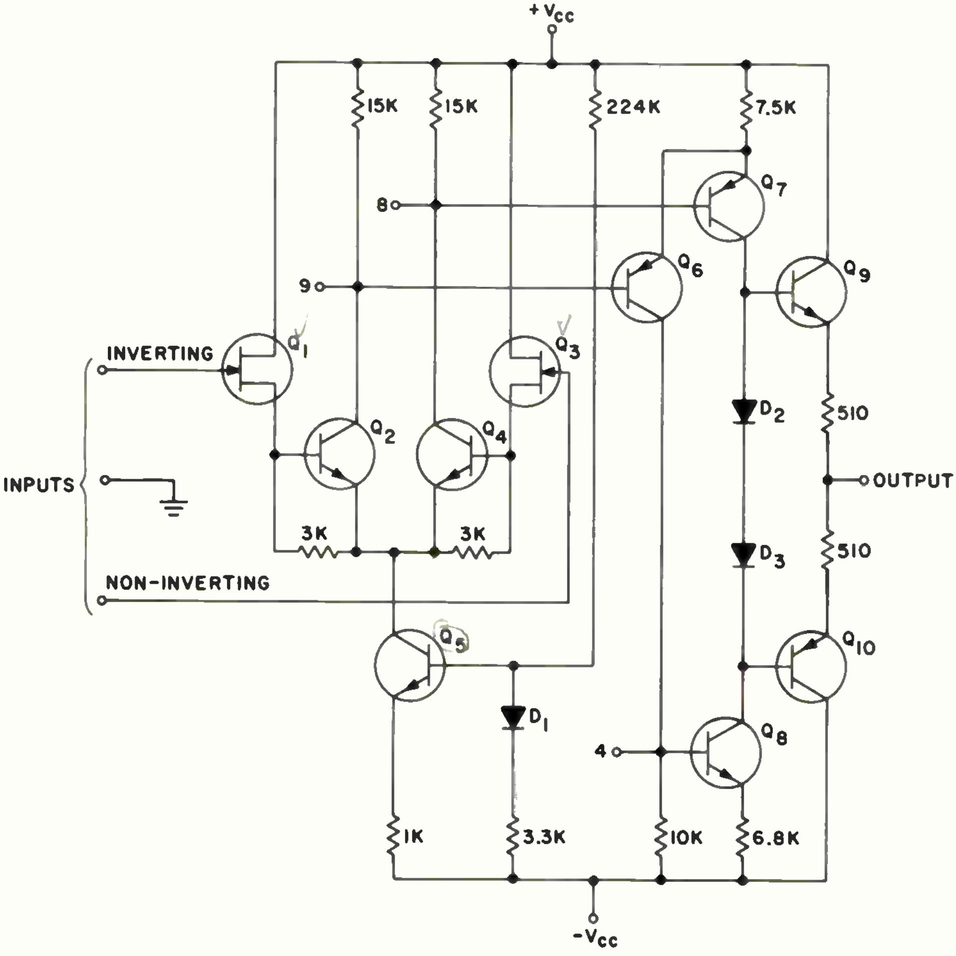


Fig. 25. Operational amplifier with FET's in input.

the field effect transistor is similar to a vacuum tube in its input impedance characteristics. You can typically obtain hundreds of megohms input impedance from a field effect transistor. Using this compound stage with field effect as well as bipolar transistors, the problems of input offset voltage drift and input offset voltage are quite difficult. The field effect transistors, in particular, do not have good tracking ability with temperature (for temperatures above about 70°C, the tracking is very poor). However, for commercial applications they give extremely low values of input bias currents and extremely high values of input impedance.

The 15K resistors in the collector circuits of Q_2 and Q_4 are the load resistors of the first differential stage. The two collectors of Q_2 and Q_4 are connected respectively to the bases of transistors Q_7 and Q_6 which form a modified differential amplifier. Transistors Q_6 and Q_7 are PNP devices. Here we use the complementary symmetry connection to obtain a dc level shift. This achieves direct coupling and level shifting at the same time. The output stage or power stage is formed by transistors Q_8, Q_9 and Q_{10}. The collector of Q_6 is connected to the base of Q_8, while the collector of Q_7 is connected directly to the base of Q_9. Q_9 and Q_{10} form a class B output stage. Q_8 is used to produce an out-of-phase signal into the base of Q_{10} so that we form a push-pull stage with Q_9 and Q_{10}. The output stage is essentially a complementary emitter-follower. Diodes D_2 and D_3 are placed between the two bases to reduce crossover distortion.

In a class B amplifier the transistors are biased to cutoff, conducting only on one-half cycle of the input driving signal. In a complementary symmetry class B amplifier, the positive half-cycle is amplified by the NPN transistor while the negative half-cycle is amplified by the PNP transistor. This is true for Q_9 and Q_{10} in Fig. 25; when one is conducting, the other is cut off.

With this arrangement, crossover distortion occurs. It is caused by the emitter-base characteristics of the transistors used. A silicon transistor requires a voltage of .6 to .7 volt across this junction before it conducts. With only .2 volt of forward bias, it is still cut off. The depletion layer in the junction effectively causes the transistor to be reverse-biased by about .6 to .7 volt. For that reason, a transistor is not operated exactly at cutoff as required for class B conditions. The result is that the input waveform must go more positive or more negative than .6 to .7 volt before the NPN or PNP transistor will conduct. During the zero crossing period of the input sine wave, neither transistor conducts, so the output signal appears as in Fig. 26.

This distortion can be eliminated by applying just enough forward bias to the transistors so that they operate right on the threshold of conduction, a condition required for proper class B operation. In Fig. 25 diodes D_2 and D_3 provide this forward bias. Each of these silicon diodes has a drop of .6 volt, for a total of 1.2 volts between the bases of Q_9 and Q_{10}.

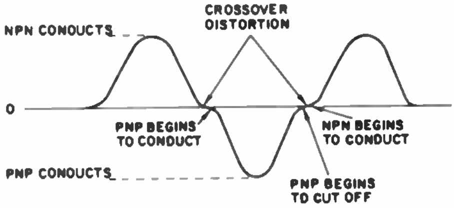


Fig. 26. Crossover distortion in a class B transistor amplifier.

This is just enough to overcome the depletion layer effects of Q_9 and Q_{10} in series. Now when Q_7 and Q_8 drive Q_9 and Q_{10} in the proper direction, they will conduct without producing the crossover distortion. The output is taken from the common emitters Q_9 and Q_{10}, through 510-ohm resistors which are there for short circuit protection.

In this amplifier we have seen several techniques. One of them is the use of field effect transistors in the input for high input impedance and low input bias current. Another is the use of an active current source. The second stage is formed of PNP transistors to obtain level shifting and some degree of gain. The last stage is a class B push-pull stage formed with a complementary pair of transistors.

To obtain an idea of the level of performance of the op amp just described, let's look at some of its characteristics: open-loop voltage gain, 100 db; input impedance, 100,000 megohms; input bias current, 20 picoamps; input offset current, 2 picoamps; input offset voltage, 10 millivolts; output voltage swing, 50 volts peak-to-peak. In this amplifier the voltage gain, input resistance and input bias current are considerably better than in the other one. However, the input offset voltage of 10 millivolts is not as low as it was in the previous amplifier.

IMPROVED OUTPUT STAGES

One of the most important op amp requirements is that it be able to produce a fairly high amount of output voltage into a low value of resistance. What this means is that a power amplifier must be used. The output stage in most op amps can supply a reasonable amount of power to a load, but for some applications, an external power booster amplifier must be used.

A typical booster output stage of an op amp is shown in Fig. 27A. This circuit is basically a current amplifier which provides wideband unity gain and peak currents up to ±200 milliamps into a 50-ohm load. Many common op amps can produce only a maximum of ±10 volts across a resistor of 3K or 4K. As you can see, this represents a very small amount of current. While using the technique that we will describe, currents of much higher values can be driven into a much lower load resistance. This configuration does not provide any voltage gain; the output voltage will be equal to the input voltage from an op amp.

The circuit in Fig. 27A is basically a set of cascaded complementary emitter-followers. It is made complementary so that the emitter-base voltage drops of Q_1, Q_3 and Q_2, Q_4 cancel each other. This makes the output voltage equal to the input voltage. The amplifier then has exactly unity gain. But because of its high input impedance and low output impedance, the circuit provides power amplification. When the output voltage from an op amp is applied to the input, the output voltage and polarity from the booster will be exactly the same. However, it is now capable of driving a larger current through the load than the op amp is.

Assume that the input to the booster circuit is at ground. This means that both transistors Q_1 and Q_2 become forward-biased. The voltage between the input and the emitter of Q_1 and Q_2 will be approximately .6 volt. This voltage is applied to the bases of Q_3 and Q_4. However, this voltage is insufficient to cause conduction of Q_3 and Q_4 so no current flows through the output load.

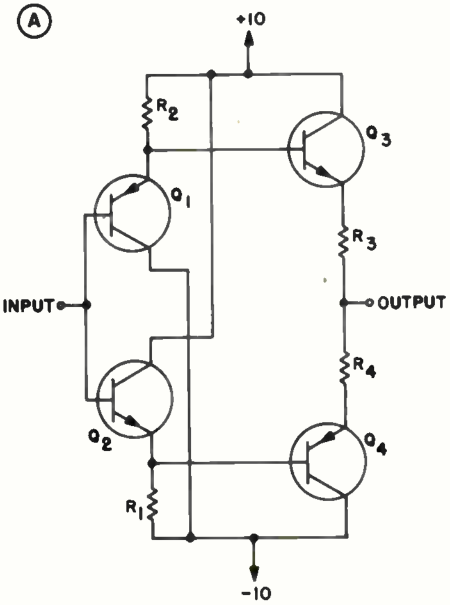


Fig. 27A. A current booster amplifier.

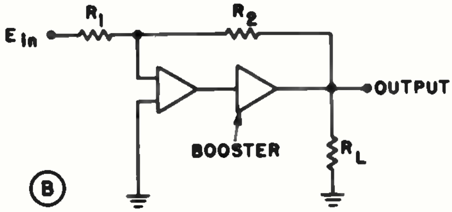


Fig. 27B. How the booster is normally connected to an op amp.

The output voltage at this time is essentially zero.

Now assume that we apply an input voltage of −5 volts. This causes transistor Q_1 to conduct more, producing a voltage of approximately −4.4 volts at the emitter of Q_1 and the base of Q_3. This voltage reverse-biases Q_3 so that it is cut off. The −5 volts at the input causes Q_2 to conduct less. The emitter voltage of Q_2 is approximately .6 volt more negative than the input, or −5.6 volts. This causes the emitter-base junction of Q_4 to conduct. Therefore, the output voltage is approximately .6 volt different, making the output −5 volts. The emitter-base voltage drop of Q_4 effectively cancels the emitter-base drop of Q_2, making the output voltage equal to the input voltage.

When +5 volts is applied to the input, Q_1 conducts less and the voltage at the base of Q_3 becomes approximately +5.6 volts. Q_3 conducts and its emitter is .6 volt less than its base, so the output voltage is +5 volts. As you can see, this is a unity gain dc power amplifier. Resistors R_3 and R_4 in the circuit are generally low in value so they do not contribute substantially to a change in the output voltage. They are used primarily for short-circuit protection. If the output accidentally short-circuits, the current flow through transistors Q_3 and Q_4 will be limited by R_3 and R_4.

For proper operation of this circuit, the emitter-base voltage characteristics of all the transistors must be closely matched so that their effects will cancel. The greatest error is introduced because the emitter-base voltage drops for NPN and PNP silicon devices are slightly different. For example, the V_{BE} of the NPN will be .6 volt; the V_{BE} of the PNP transistor will be .64 volt under the same conditions of bias. The difference would be .04 volt. This small error is generally of little consequence. Its effect can be minimized by using the booster amplifier within the feedback loop of the op amp to which it is connected. Fig. 27B shows how the booster is normally connected. The output of an op amp is fed into the booster and the load connected to the booster output. Instead of the normal feedback resistance being connected from the inverting input to the op amp output, the normal connection to the op amp output is connected to the booster. The small offset voltage produced by the imperfectly matched transistors is somewhat overcome by the use of this negative feedback.

CHOPPER STABILIZED AMPLIFIERS

A chopper stabilized amplifier is a dc amplifier in which modulation techniques are used to minimize the effects of drift. Variations in the temperature, power supply voltages and component characteristics will cause the output voltage of a dc amplifier to drift. This is an undesirable condition as it introduces an error in the output. Careful circuit design and accurate matching of components aid in minimizing drift. However, for critical applications it must be reduced further. To do this, the dc input to be amplified is passed through a chopper where it is converted into a square wave in the audio frequency range. This square wave is amplified by a standard ac amplifier. The ac output then is rectified, or converted back into dc, by the chopper; the resulting dc voltage is amplified in the standard dc amplifier.

It is the drift in the input stage of a dc amplifier that gives us the most trouble. The small drift voltage that occurs will be amplified many times by the remaining stages of amplification. Therefore, even a small input drift voltage can appear as a large offset at the output. If we can minimize the effect of drift in the input stage, then any drift in the remaining amplifier stages will have a minimum effect on the output voltage. We do this by converting the dc input voltage to ac early in the amplifier, where drift has no effect. We then convert this back to a dc signal of substantial amplitude and feed it the rest of the way through the dc amplifier.

Most op amp applications can make use of the standard unstabilized circuitry. However, for very critical applications, chopper stabilization is used to reduce drift to practically zero.

Fig. 28 shows a chopper stabilized op amp. The dc portion of the amplifier consists of the differential stage made up of Q_1 and Q_2. Transistor Q_3 and its associated components make up a temperature-compensated current source for the differential input stage. The output of the differential stage is taken from the collector of Q_2 and fed to a complementary amplifier stage, Q_4. Additional gain is produced in this stage and its output is coupled to transistor Q_5 and the emitter-follower output circuit.

The input signal applied to this circuit is actually fed to two places. First the high-frequency components of the input are passed through capacitor C_5 to the differential input stage. Any dc at the input is eliminated by capacitor C_5. The values of capacitor C_5 and resistor R_3 are chosen to act as a high-pass filter that passes only frequencies above a certain cutoff point. All dc and very low-frequency ac signals are passed through R_1 and C_1, a low-pass filter, to a chopper.

As you recall from a previous lesson, a chopper is nothing more than a switch that alternately connects and shorts out the dc signal at the input of an ac amplifier. In this circuit transistor Q_6 is used as a shunt switch. When Q_6 is open,

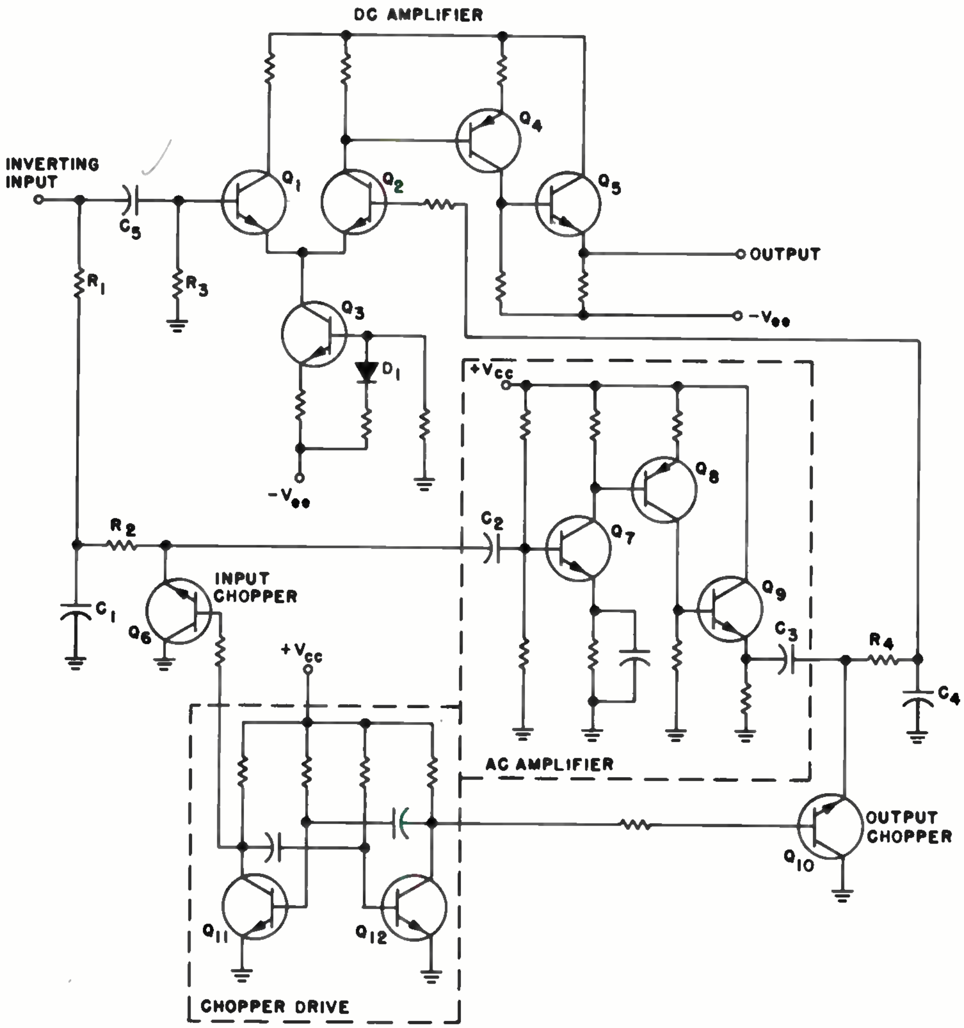


Fig. 28. A chopper-stabilized amplifier.

it has no effect on the circuit and the input voltage is applied directly to the ac amplifier through C_2. When Q_6 conducts, it shorts out the signal so that none is applied to the ac amplifier. Transistor Q_6 is turned off and on very rapidly by a free-running multivibrator circuit used as a chopper driver. This consists of transistors Q_{11} and Q_{12} and their associated components. The outputs at the collectors of Q_{11} and Q_{12} are square-wave signals that switch between ground and $+V_{CC}$. This is used to turn transistor Q_6 off and on. A rate of about 400 Hz is used.

Notice that in this circuit Q_6 is connected in a configuration inverted from that normally used. To turn a transistor on, we usually forward-bias its emitter-base junction. In this circuit we are forward-biasing the collector-base junction. Most transistors are somewhat symmetrical; the collector can be used as the emitter and vice versa. By using this connection, there will be an extremely low voltage drop between the emitter and collector when the transistor is turned on. This permits the transistor to function as an almost perfect on/off switch. When it is on, its resistance is practically zero; when it is off, almost infinite.

The 400 Hz signal appearing at the emitter of Q_6 is passed through the ac amplifier made up of Q_7, Q_8 and Q_9. Here it is amplified and fed to the output chopper, which is another inverted transistor, Q_{10}. Q_{10} effectively rectifies the ac output while R_4 and C_4 filter it into a dc voltage to be applied to the other input of the differential amplifier. Here the dc signal undergoes further amplification in transistors Q_2, Q_4 and Q_5.

Because of the tremendous improvements recently made in electronic components and circuit techniques, chopper stabilized amplifiers are actually being used less. It is now possible to obtain closely matched transistors and stable power supplies that reduce drift effects to a point where chopper stabilization is unnecessary. In fact, many of today's integrated circuit op amps have characteristics which approach those of a standard chopper stabilized amplifier. However, for extremely critical operations, chopper stabilization may be used to completely eliminate the effects of drift.

SELT-TEST QUESTIONS

(x) Name three ways a high input impedance can be obtained in an op amp.

(y) What is the purpose of a booster amplifier?

(z) What transistor characteristic causes crossover distortion in a class B amplifier?

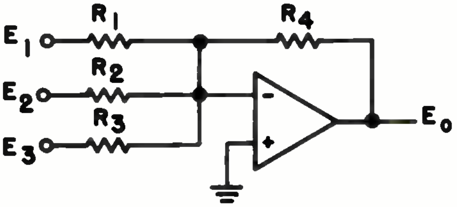
3-18-76

Common Uses

Today amps are used in a wide variety of ways. They appear in almost every phase of electronics because they are capable of performing so many useful functions. The op amp is a key element in the analog computer because it can perform so many useful mathematical calculations. It can perform multiplication and division by a constant simply by selecting the gain. It can also add or subtract. Since one of the major uses for op amp is performing mathematical operations, we will show you several of these useful applications.

MATHEMATICAL OPERATIONS

A typical op amp and summer is shown in Fig. 29. This circuit is basically that of the simple inverting op amp you studied before. The only difference is that we have added more than one input resistance. In this case we have added three, and to each supplied an input voltage. The op amp will sum the three input voltages after multiplying each by a gain that is the ratio of the feedback resistance divided by the associated input resistance.



$$E_0 = -\left[\frac{R4}{R_1}(E_1) + \frac{R4}{R_2}(E_2) + \frac{R4}{R_3}(E_3)\right]$$

Fig. 29. An op amp summer.

The mathematical output expression is shown in Fig. 29. Notice that the negative sign indicates that the sum is inverted. This amplifier circuit can be used to perform algebraic addition or subtraction operations. Any number of input resistances may be connected to the summing junction.

To show how this circuit works, let's assume some values for R_1, R_2, R_3 and R_4 in Fig. 29. Assume that all the resistors are 100K. Next assume the input of E_1 equals 2 volts, E_2 equals 3 volts, and E_3 equals 4 volts. Now, using all of these values, what is the output voltage? Find its magnitude and its polarity.

To solve this problem, all you have to do is fill in the appropriate values in the output expression shown in Fig. 29. We will do this after trying to understand exactly what is happening in this circuit. Keep in mind that each of the input voltages is going to be multiplied by a coefficient that is the gain of the amplifier for that input. Recall that the gain of the op amp is a function of its feedback and input resistance ratio. However, since we have made each input resistor the same size as the feedback resistor, this ratio will be 1:1. Therefore, in this circuit the output voltage is equal to:

$$E_o = -\left[\frac{100K}{100K}(2) + \frac{100K}{100K}(3) + \frac{100K}{100K}(4)\right]$$

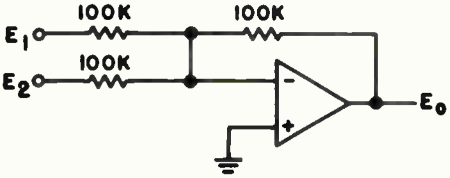
$$E_o = -\left[1(2) + 1(3) + 1(4)\right]$$

$$E_o = -(2 + 3 + 4) = -9$$

The solution to this problem simply involves basic addition. The amplifier performs the addition. Just keep in mind that the amplifier circuit still inverts and that this inversion must be considered when the absolute algebraic or polarity of the signal is important.

In a previous section you were introduced to the differential op amp circuit that is used to take the difference between two input voltages. This circuit could also be used to perform subtraction. However, we can also use a summer circuit to perform subtraction.

Fig. 30 shows a two-input summer that can be used for subtraction. Notice in this circuit that both the input and feedback resistances are equal so that the input voltages are multiplied by 1. To use the summer to subtract, we must feed voltages of opposite polarity into the two inputs. The op amp produces the difference between the two input signals as an output with a polarity opposite to the larger voltage.



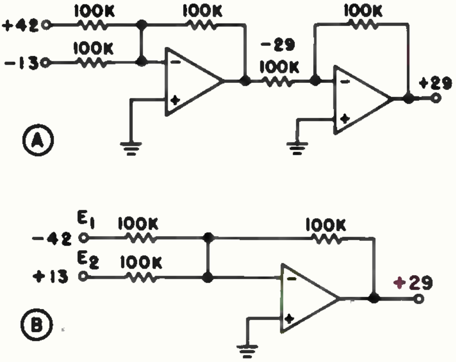
$$E_0 = -(E_1 + E_2)$$

-27 +15

Fig. 30. Two-input summer for subtraction.

As an example, let's subtract 18 from 27. E_1 will be −27 volts and E_2 will be 18. Since the polarities of the two voltages are different, the amplifier is going to produce an output voltage equal to the sum of the two (−9 volts). Because the larger voltage is negative, the output voltage will be inverted by the amplifier to become positive. The op amp performs algebraic addition; with it we can add numbers of any polarity. When we add numbers of opposite polarity we are producing subtraction. In other words, the process of subtraction is a form of algebraic addition. This op amp circuit inverts so that the polarity of the output voltage is significant. Therefore be sure to invert the output voltage that you observe to obtain the true algebraic value.

By properly assigning the polarities of the input voltages the inverting characteristics of the amplifier can be used to provide proper polarity output. For example, if we wish to solve 42 − 13, one way is to make 13 a negative voltage and 42 a positive voltage. As in Fig. 31A, the circuit will produce an output voltage equal to −29. Note that the input and feedback resistances are all equal to one another so that no coefficient multiplication takes place. Although this circuit produces the proper magnitude output voltage of 29, the polarity is algebraically incorrect. The reason for this is simply the inversion of the op amp. We can correct the situation by passing the signal at the output of the summer through a simple unity gain inverter. This will produce the proper output voltage without changing the magnitude.



$$-(E_1+E_2) = -(-42+13) = (42-13) = 29$$

Fig. 31. Two ways of producing correct algebraic subtraction.

However, we can produce the proper polarity output voltage with a single summer amplifier if we correctly assign the polarities of the input voltages. This is shown in Fig. 31B. The two input voltage magnitudes are the same as before, 42 and 13. However, we make the larger of the two voltages the negative so that the polarity of the inverted output will be correct. This way we let the inverting characteristics of the amplifier work for us.

CALCULATING OP AMP NETWORKS

By now you should be able to calculate the output voltage and polarity of an op amp network. Knowing the values and polarities of the input voltages and the values of the input and feedback resistances, you should be able to take a circuit like that in Fig. 32 and compute the output voltage and polarity. Notice that this circuit uses a wide variety of op amp configurations. While at first this network may seem somewhat complex, keep in mind that it uses nothing but the simple individual op amp circuits that you have already studied. By breaking the problem down and calculating the voltage at each point in the circuit, it is very easy to arrive at the correct output voltage and polarity. Let's go through this circuit and calculate the output voltage, assuming the input voltages shown.

Amplifier 1 is a simple inverting amplifier whose gain is the ratio of the feedback to input resistors. This ratio is 40K/25K = 1.6. This amplifier multiplies the input voltage by a gain of 1.6. Multiplying our input voltage of 40 by 1.6 gives us an output voltage of 64 volts. Keep in mind that the amplifier inverts so the output is negative since the input voltage is positive. This means that −64 volts appears across the potentiometer. This pot is set to a coefficient k of .2. This simply indicates that 20% of the voltage applied to the pot is tapped off and appears at the arm. To find the voltage at the arm we simply multiply −64 by .2 to get −12.8 volts. This voltage is applied to one end of a differential amplifier. Notice the differential amplifier uses all 10K resistors so that no gain is provided. Instead, the output voltage will be the difference between the two input voltages.

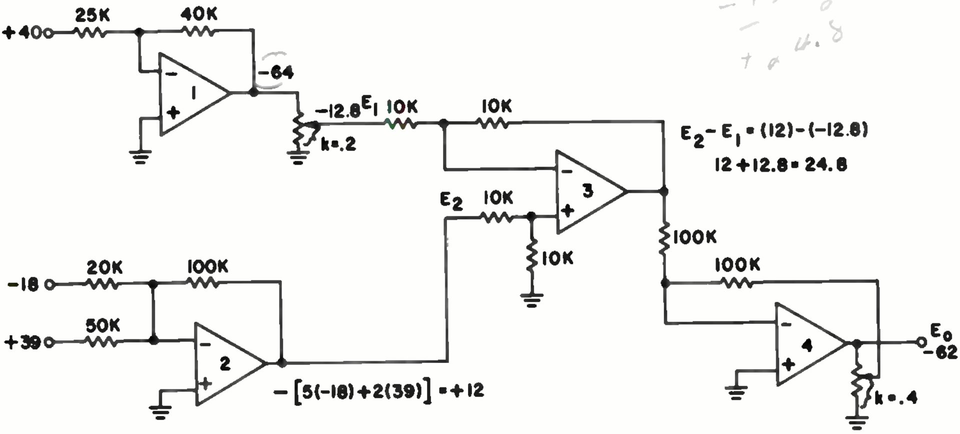


Fig. 32. An analog computing circuit using a variety of op amp circuits.

Amplifier 2 is a summer to which two input voltages are applied. The resistor values in the circuit provide gain multiplication for each input. Again the gain of each input is equal to the ratio of the feedback to the input resistor. The gain of the upper input is 100K/20K = 5. This means that the input voltage, −18, is multiplied by a gain of 5. The gain of the lower input is 100K/50K = 2, meaning that the input voltage, +39, is multiplied by 2. Making the calculation using the standard output formula, we get an output voltage of 12.

Now we have both inputs to the differential amplifier and we can calculate the output. Recall from your knowledge of this circuit that the output is equal to $(E_2 - E_1)$, or the lower input voltage minus the upper input voltage. Plugging our two input voltage values into this formula, we find that the output voltage is 24.8. Notice that since we are subtracting two input voltages of opposite polarity, the overall effect is algebraic addition. The output of amplifier 3 then is a positive 24.8 volts. This is now fed to amplifier number 4, where it is further multiplied in gain. Notice that the circuit used here is the one whose gain is determined by the coefficient of the output potentiometer. The gain of this circuit is equal to 1/k = 1/.4 = 2.5. The output voltage then is the inverted product of 24.8 multiplied by 2.5, or 62 volts.

INTEGRATOR CIRCUITS

In several previous lessons the subject of integrators was discussed. An integrator, in its simplest form, is a resistor-capacitor network whose time constant is made long with respect to the period of the input signal applied to it. This circuit, then, produces an output that is a function of the mathematical integral of the input signal. Integration is a mathematical function; specifically it is a form of calculus. However, we'll take a simpler approach (eliminating a calculus discussion) toward understanding the integrator circuit.

A simple integrator circuit is shown in Fig. 33. The input voltage is applied across a resistor and capacitor connected in series and the output voltage is taken from across the capacitor. If the input signal applied to this integrator network is a sine wave, the output signal will also be a sine wave. Because of the reactance in the circuit, the output voltage will be out-of-phase with the input voltage. Specifically, the output voltage will lag the input voltage by some angle between zero and 90°. The longer the time constant of the circuit, compared to the period of the incoming signal, the closer the output voltage approaches the 90° lag point. At this time the reactance of the capacitor is generally so low, compared to the resistance value, that the output

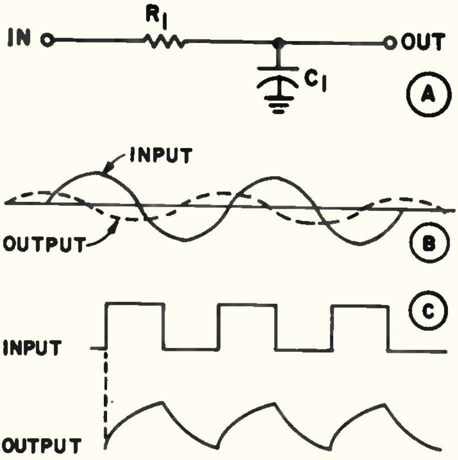


Fig. 33. A simple R-C integrator (A), sine wave input/output (B) and square wave input (C).

voltage is much smaller than the input voltage. Theoretically, if the phase shift were a total of 90°, the output voltage would be zero. However, a practical integrator is one whose phase shift approaches 90° closely, but also one that still has a measurable output voltage.

If the input voltage applied to an integrator is a square wave like that shown in Fig. 33C, the output voltage will be a triangular or sawtooth type waveform. The larger the time constant, the closer the output approaches a linear sawtooth or triangular waveform.

The integrator circuit shown in Fig. 33 is a useful network. It can be used to perform phase-shifting and wave-shaping operations. However, it is limited in that its output voltage is much smaller than its input voltage and it does not provide perfect integration. In many applications it is desirable to have exactly a 90° phase shift, or a perfectly linear sawtooth or triangular wave output. The op amp integrator that we will describe next can be used for such applications.

A typical op amp integrator is shown in Fig. 34. This is the standard op amp configuration except that we use a feedback capacitor instead of a feedback resistor. The result is a nearly perfect integrator circuit. Disregarding amplifier phase shift, the output is shifted exactly 90° when a sine wave is applied to the input of this circuit. The output amplitude can be adjusted to a desired level by choosing the proper values of resistance and capacitance. When a square wave or dc step voltage is applied, the output is nearly a perfect linear sawtooth or ramp waveform. The rate of change of the output voltage depends upon the input voltage and the gain of the integrator which is determined by the R-C values in the circuit.

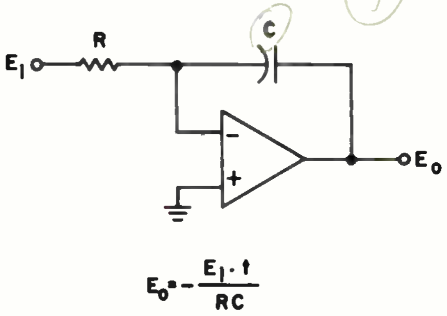


Fig. 34. An op amp integrator.

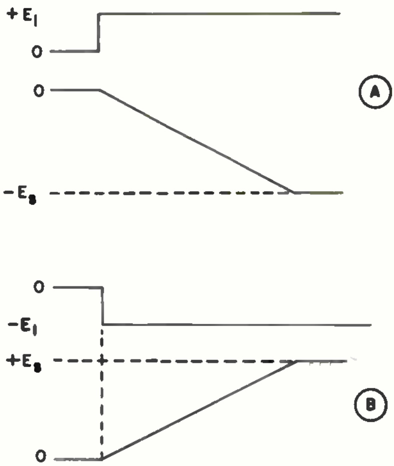


Fig. 35. Integrator input-output waveforms.

Now let's take a look at the operation of the op amp integrator circuit of Fig. 34. We are going to apply a step voltage to the input where the voltage switches rapidly from zero to some dc voltage level and remains there. The output waveform of the integrator, under these conditions, is shown in Fig. 35. In Fig. 35A, both the input voltage (E_I) and the output voltage are zero.

When the input voltage steps rapidly to the positive voltage level E_1, the output begins to rise slowly in a negative direction. The change of voltage is linear with respect to time, producing a straight negative-going ramp. As long as the input voltage is held at the E_1 level, the output will slowly rise due to the charging of the feedback capacitance through the input resistor. Soon we will reach a point where the output voltage can no longer continue to increase due to the saturation of the output amplifier of the op amp. When this occurs the output levels off at an output voltage $-E_S$, which is equal to or slightly less than the negative power supply voltage of the op amp.

Fig. 35B shows the input and output waveforms for a negative-going step voltage input. When the input voltage steps to a negative E_1 level, the output voltage begins to rise linearly from zero. As long as voltage is applied, the output will increase in a straight line to eventually reach the saturation point that is nearly equal to the positive supply voltage of the op amp.

The value of the output voltage is very predictable if we know the values of the input resistor, the feedback capacitor, the input voltage and the time during which the input voltage is applied. All of these factors are related by the formula:

$$E_{out} = -\frac{1}{R\text{-}C}(E_1)(t)$$

This formula tells us the value of the output voltage at a specific time (t) after input voltage E_1 is applied. The 1/R-C value is the gain of the integrator stage. The gain of this circuit is equal to the reciprocal of the time constant. If we are using a 1 mfd capacitor and a 1 megohm input resistance, the integrator gain is $1/(10^6 \times 1 \times 10^{-6}) = 1$. With a gain of 1, the output voltage with a step voltage input is simply equal to $-E_1(t)$.

Let's assume that we have an input voltage of +10 volts and that we allow the circuit to integrate for a period of 5 seconds. To determine the output voltage, we multiply the input voltage by the time and invert the result. In this case, $E_{out} = -10 \times 5 = -50$ volts. We can stop the integration after 5 seconds by removing the input voltage or by shorting the capacitor.

Fig. 36 shows the output waveforms you can expect. The waveform at A shows the step voltage input that switches from zero to +10 volts. The output voltage begins to increase in negative value. If the input is allowed to be present for 5 seconds, the output voltage will go to −50 volts. If we remove the input voltage at this point, the output will remain at its −50 volt level. This is

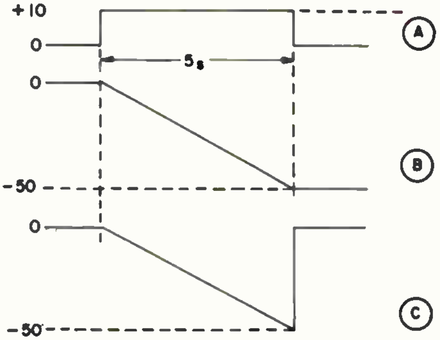


Fig. 36. Integrator step input (A), output where input is removed after 5 seconds (B) and output where feedback capacitor is shorted after 5 seconds (C).

because the capacitor retains the charge it received (−50 volts) while the input was connected. Over a long period of time, the charge on this capacitor will leak off due to the internal resistance of the capacitance, the input impedance of the op amp and other factors.

Fig. 36C shows the result of shorting the output feedback capacitor after a 5 second period. The output voltage again goes negative to reach a value of −50 at the end of 5 seconds. If we short the output capacitor with a switch of some type, the capacitor discharges quickly through the short circuit. The output voltage drops to zero despite the fact that the input is maintained at this value.

What happens to the output voltage when we change the gain of the amplifier? Let's change the values of the input resistor and feedback capacitor and note the effect this has on the output voltage when we integrate the +10 volt dc input for a period of 5 seconds. Assume that our new input resistance is 100K-ohms and our feedback capacitor is .1 mfd or 10^{-7}. The R-C time constant then is 10^5 X 10^{-7} = 10^{-2}. Then the gain of the integrator is 1/R-C = $1/10^{-2}$ = 1/.01 = 100. We now multiply our input voltage by 100 and the time the input voltage appears at the integrator. The output voltage should theoretically rise to a value of 10 X 100 X 5 = 5000 volts. However, this is an unreasonable value because of the output voltage swing limitations. Even if this is a high voltage amplifier where the output voltage swing may be ±100 volts, the output will quickly rise and saturate at its negative level shortly after the input voltage is applied.

The gain of an integrator, the input voltage value and the time the integrator is allowed to observe the input voltage determine the rate at which the output voltage changes. If the gain and the input voltage are high, the output voltage changes rapidly. If we are not careful to control the input voltage, gain and time duration of integration, it is quite easy to saturate the amplifier or to cause it to try to produce an output voltage beyond its capabilities. Fig. 37 shows the output voltage of an integrator with a −10 volt input step. The outputs produced with high, medium and low gains are shown. The high gain is a result of a short R-C time constant. The capacitor charges quickly, so the output voltage rises rapidly and saturates at time t_1. Making the R-C time constant longer lowers the gain. Since it takes the capacitor longer to charge, saturation doesn't occur until time t_2. A very low gain, meaning a long time constant, produces a very gradual output ramp that reaches saturation at t_3.

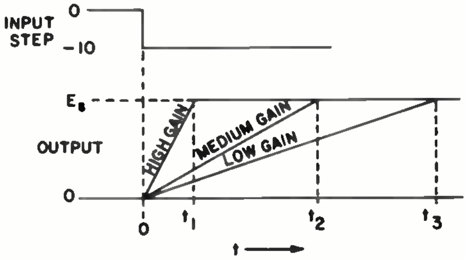


Fig. 37. How integrator gain affects the output ramp.

Fig. 38 shows how the op amp can be used with sine wave signals. If we assume that the feedback capacitor is 1 mfd and the input resistor is 1 megohm, the gain of the op amp is 1/R-C = $1/(10^6$ X $10^{-6})$ = 1. This means that the output will be equal to the input. However, because the circuit is an integrator, the input and output waveforms will be out-of-phase. A perfect integrator would produce an output that lags the input by 90°. Keep in

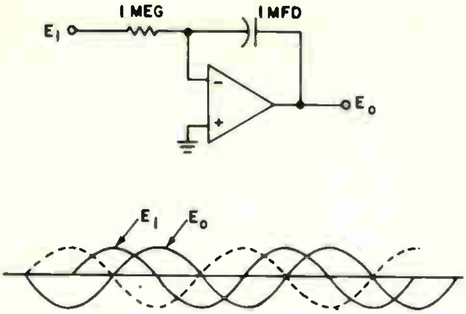


Fig. 38. Integrator operation with sine wave signals.

mind that our op amp integrator also inverts the signal; the output is actually shifted by 90° and then inverted 180°.

The input and output voltages of the integrator are also shown. The output voltage, as it would appear without inversion, is marked by the dashed line. As you can see, it lags the input signal by 90°. However, inversion adds another 180° phase shift, which causes the output voltage to appear as though it is leading the input signal by 90°. We call the output waveform a cosine waveform to distinguish it from the sine wave input. By adjusting the values of input resistance and feedback capacitance, the gain of the amplifier can be adjusted to produce any desired output amplitude within the amplifier's capability.

3-23-72

ELECTRONIC COMPARATORS

An electronic comparator is a circuit that compares one voltage with another and produces an output signal that indicates when the two input voltages are equal. A good electronic comparator will also produce an output signal that will permit you to know whether one of the input signals is less than or greater than the other. One of the input signals to the comparator is the reference signal. It is the standard by which we will compare another input signal, generally a changing or varying signal.

The simplest form of a comparator is the diode circuit shown in Fig. 39. A diode is biased through a resistance with a 20-volt battery which represents the reference voltage. We are going to compare this reference voltage with the input signal, applied to the cathode of the diode that is a positive-going ramp voltage. This could possibly be the output from an integrator being driven from a negative dc source.

With the input voltage at zero, the diode is forward-biased. If we assume this to be a perfect diode that has no voltage drop across it, the output voltage will also be zero. As the input voltage begins to rise, the diode still conducts; therefore, the input is effectively connected directly to the output through the diode.

The output exactly follows the shape of the input signal. The output remains the same as the input only while the input voltage is less negative than the reference voltage, keeping the diode forward-biased. As soon as the input voltage reaches a value of 20 volts, the diode no longer conducts; there is insufficient voltage across it to cause it to be forward-biased. As the input voltage rises beyond 20, the diode is still cut off so the output voltage remains at 20 volts. The

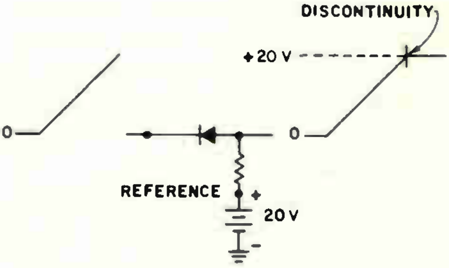


Fig. 39. A simple comparator circuit.

output, in effect, sees the 20 volts from the reference battery through the resistor.

The output signal flattens off at this point. The point where the waveform stops rising in voltage and flattens out is known as a discontinuity. As long as the input voltage is less than the reference voltage, the output follows the input. However, when the two are equal, a discontinuity in the output occurs. This discontinuity represents the point where the reference and input voltages are equal. Beyond this the output waveform flattens out, indicating that the input voltage is greater than the reference.

While the circuit of Fig. 39 is definitely a comparator, its usefulness is somewhat limited. In a practical circuit, there is a finite voltage drop across the diode. For a silicon diode this drop may be .6 or .7 volt. As a result the diode will not stop conducting until the input voltage is approximately .6 or .7 volt above the reference voltage. For this reason there is a substantial error in the comparison. This is particularly true if the reference voltage is a small voltage that is the same order of magnitude as the diode voltage drop. For very large voltages, the percentage error would be much smaller.

In addition, the output waveform is not in the most easily used form. In a practical circuit, the discontinuity point is not a sharp and clearly defined point. Because of the stray capacitance in this circuit, the point is rounded and introduces some ambiguity in the exact point of equality. This circuit is adequate for simple comparisons, but for critical comparisons, a more sophisticated circuit is required.

Consider for a moment how we may use a differential amplifier as a comparator. A differential amplifier is normally designed to handle dc signals. Therefore we may apply the reference voltage to one of the differential inputs. Since the output of the amplifier is equal to the difference between the two inputs multiplied by the gain, applying a varying signal to the other input will make the differential amplifier output indicate when the two are equal. When the two signals are equal, the output of the amplifier will, of course, be zero. The higher the gain of the amplifier, the larger the output voltage swing will be for a small difference between the two input signals. Remember that this circuit amplifies the difference voltage between the two input signals.

According to this principle an op amp operated in the differential mode with no feedback should provide excellent comparison. By using the full open-loop gain of the amplifier, only millivolts (or perhaps microvolts) of difference signal is required to cause the amplifier output to swing between its two maximum output voltage limits.

Fig. 40A shows an op amp connected as a comparator. Notice that absolutely no feedback connection is provided. The reference signal is connected to one of the inputs while the varying signal, to be compared to the reference signal, is applied to the other input.

If we use the input signal assumed earlier for the simple comparator, we can get some idea as to the sensitivity of this circuit. When the input voltage at the inverting input is 0 volts, the reference being 20 volts, the difference signal is 20 volts. With this much input signal multiplied by the full open-loop gain of the amplifier, the output will swing to its positive saturation level.

With an open-loop gain of 10,000, the output voltage would try to swing toward a value of 200,000. However, the ampli-

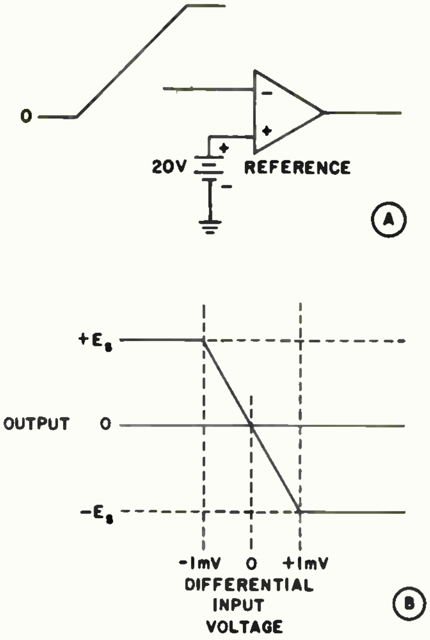


Fig. 40. An op amp comparator (A) and its output voltage (B).

fier will simply saturate at its positive output swing point. You can see this in the graph of Fig. 40B. As the input signal begins to rise from zero in a positive direction, the difference voltage between the two inputs grows smaller. However, during most of the rise, the difference voltage between the two is still large enough to keep the amplifier output in saturation.

Soon we begin to reach a point where the input voltage approaches the value of the reference. When the input voltage becomes equal to the reference voltage, the output of the amplifier will be zero. As you can see from the graph in Fig. 40B, the output voltage drops from its positive saturation level to zero when the two voltages are equal.

As the input voltage continues to swing in a positive direction, it becomes greater than the reference voltage and the difference signal between the two is amplified. As soon as the difference signal reaches a large enough value, the output of the amplifier swings to the negative saturation region. As you can see from the curve, the gain of the amplifier is so high that it takes only a 1 millivolt difference between the two input signals to cause the amplifier output to swing to one of its saturation levels.

For that reason the sensitivity of this circuit enables us to detect the equality between two signals within very close ranges. With only 1 millivolt of error, it is possible to compare very low level signals with good precision. When the output of the comparator sets at one of its saturation levels, it means that the input signal is either greater than or less than the reference voltage. The other saturation level is reached whenever the input signals are again unequal. When the two input signals are equal, the output of the comparator is zero. Simply by looking at the output signal, you can tell whether the input voltage is less than, equal to, or greater than the reference voltage.

There are some very important facts to keep in mind here. The rapid switching of the op amp output is due to its high gain or sensitivity. Remember that we are amplifying the difference voltage between the two inputs. With the high open-loop gain, the output can swing from its negative to positive output saturation level with only an extremely small difference signal. For most typical op amps, a difference voltage in the millivolt region is sufficient to cause the amplifier to swing from one extreme to the other. There is some error introduced, but it is extremely small; it is negligible for almost all practical electronic circuits.

The sensitivity of the op amp com-

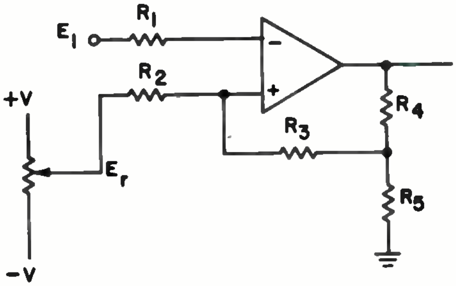


Fig. 41. Adding feedback to raise the trigger level and minimize the effects of noise.

parator can also be a disadvantage. Many times noise signals appearing on the inputs can cause the comparator to trigger falsely, producing undesirable output voltage transitions.

To overcome the noise sensitivity of the comparator, we can add feedback to the circuit. Fig. 41 shows a differential op amp comparator where the input voltage E_1 is applied to the inverting input through R_1. The reference voltage is obtained from a potentiometer that is connected to both positive and negative power supplies. The arm of the pot can be set to any voltage between the upper (positive) and lower (negative) voltage levels and still include the zero volts at the center of the pot. This provides a convenient means of adjusting the reference voltage level for the circuit. The reference voltage is applied through R_2 to the non-inverting input of the op amp.

Let's assume that the op amp has an initial sensitivity of 10 millivolts. This means that a change or difference of 10 millivolts between the two inputs will cause the amplifier to switch from one output level to the other. If noise exceeding 10 millivolts appears on the input line, the comparator output will trigger erratically and give us a false indication of the comparison of the input and reference signals.

To get a true comparison, we apply feedback to the non-inverting input. A small portion of the output voltage is tapped off by the voltage divider made up of R_4 and R_5. The voltage is fed back through R_3 to the non-inverting input along with the reference voltage. Here the feedback voltage effectively adds to the reference voltage, increasing the amount of difference voltage required to cause the amplifier to trigger. If we feed back 15 millivolts from the output, the overall threshold for the circuit becomes 10 + 15 or 25 millivolts. This means that the difference between the two input signals must be at least 25 millivolts in order to cause the output voltage to switch from one level to the other.

This introduces a little more error in our comparison. However, the increased voltage difference required for output switching minimizes the effect that noise has on the circuit. In other words, the circuit can now tolerate a higher level of noise on the input without producing erratic switching. The feedback effectively reduces the sensitivity of the comparator but improves its noise immunity. By replacing resistors R_4 and R_5 with a potentiometer, the sensitivity can be made adjustable.

Fig. 42 shows another way of using an op amp as a comparator. The non-inverting input is connected to ground as it normally is in a standard op amp

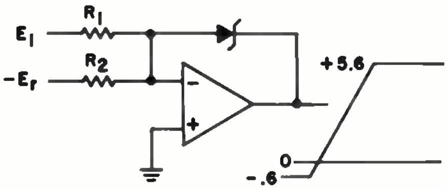


Fig. 42. Comparator made with an op amp summer.

configuration. The input and reference voltages to be compared are applied to the inverting input through summing resistors R_1 and R_2. In order for this circuit to properly perform algebraic addition (subtraction), the polarities of the two voltages to be compared must be opposites.

In the comparator circuit you studied in Fig. 40, the polarities of the input and reference voltages were the same. If the input voltage was positive, the reference voltage would also be positive. In the same way, a negative input voltage and a negative reference could also be used to obtain proper operation. Here we are effectively using the algebraic addition characteristics of the op amp to compare the two input signals. When the two input signals E_1 and $-E_R$ are equal in magnitude, the sum of the inputs at the inverting input will be zero, making the output zero. If the input voltage E_1 is greater in magnitude than the negative reference voltage, the resulting input is positive. This causes the output to swing to its negative saturation level. When E_1 is smaller, the net input voltage is negative and the output voltage swings to its positive output extreme.

In this circuit we are using a Zener diode in the feedback path. This prevents the amplifier from swinging between its two saturation levels, limiting the output voltage levels. When the output swings in the negative direction, it causes the Zener diode to be forward-biased. The output voltage is limited to .6 volt. When the output voltage swings positive, the Zener diode becomes reverse-biased in its Zener mode and holds the output voltage to a level equal to the Zener voltage. In this case we are using a 5.6 volt Zener. This practice of limiting, or clamping, the output voltage to a specific level is often used to make the output voltage of the comparator compatible with other electronic circuits that it will drive.

COMPARATOR APPLICATIONS

The op amp comparator circuits that we have discussed here have a wide variety of applications. They are useful in any situation where you want to compare the voltage level of two inputs and produce an output that detects this comparison. There are many electronic control applications where it is necessary to detect when two voltage levels are equal.

The comparator may be used to monitor the output voltage of a power supply driving a critical instrument. The reference voltage is set equal to the desired power supply output voltage while the output voltage is applied to the comparator input. As long as the output voltage is above the reference voltage, the output of the comparator is considered to be *off*. However, if the power supply voltage should drop, the comparator would detect this change in voltage and cause its output to switch to an *on* condition. The output could then be used to turn on a light that would signal a low voltage condition that may be undesirable in the system. A comparator used in this way is called a threshold detector. Comparators find a wide variety of uses in control applications such as this.

The output voltage of a comparator can also be used to make a decision regarding the *off* or *on* of a specific logic circuit, based upon the relative amplitudes of certain input and reference voltages. For example, if the input voltage is above the reference voltage, a particular electronic circuit may be permitted to operate. However, if the input voltage drops below the reference voltage, the output of the comparator either turns off the electronic circuit to prevent its operation or enables another electronic circuit to perform an alternate function.

A very common application for the voltage comparator is waveform generation. For example, the comparator can be used to change a sine wave signal into a square wave. Fig. 43 shows a sine wave signal applied to the input of a comparator. The sine wave varies symmetrically above and below zero. The dashed line in the figure represents an applied dc reference voltage. Whenever the sine wave and reference voltages are equal, the output of the comparator will switch and produce a square wave output signal. Also notice in Fig. 43 that each time the sine wave and reference voltages are equal, the output of the comparator switches to produce a clean square wave. The frequency of the square wave is the same as that of the input sine wave. However, the duty cycle of the output waveform depends upon the setting of the reference voltage. A 50% duty cycle square wave can be generated from the sine wave by making the reference input equal to zero. Whenever the sine wave voltage crosses the zero axis, the comparator will switch and produce a 50% duty cycle square wave. Remember that output clamping with a Zener diode can be used to produce desired, limited voltage levels for driving other circuitry.

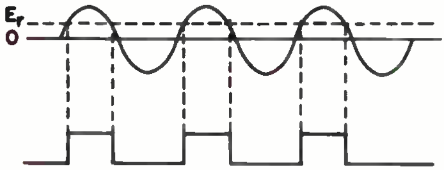


Fig. 43. Input-output waveforms of a comparator used for wave-shaping.

SELF-TEST QUESTIONS

(aa) A 3-input summer amplifier has input resistors R_1 = 10K, R_2 = 5K, and R_3 = 2K to which are applied voltages of $E_1 = -10$, $E_2 = +6$ and $E_3 = +8$. The feedback resistor R_f is 20K. What are the amplitude and polarity of the output voltage?

(ab) True or false: An op amp summer can perform any algebraic addition problem.

(ac) True or false: A summer can have any number of inputs.

(ad) True or false: The output voltage rate of change in an integrator can be varied by changing the size of the feedback capacitor.

(ae) True or false: An op amp integrator does not invert.

(af) An integrator has a feedback capacitor of 1 mfd and an input resistor of 100K. What is the gain?

(ag) If the integrator in (af) is allowed to integrate a –.3 volt input for 7 seconds, what will the output voltage be?

(ah) True or false: In a summer type comparator the input and reference voltages must be of opposite polarity.

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Tests and Measurements

The ultimate test of an op amp is its performance in the particular application for which it was selected. However, there are individual tests that can be made to test the individual specifications to determine its suitability for a given job. In this section we are going to discuss measurements of op amp characteristics. Adequate prediction of performance requires measurement of many of the parameters that will be discussed in this section.

MEASURING OPEN-LOOP GAIN

Open-loop gain of op amps can be a difficult parameter to measure; gain is usually very large and oscillation problems are often encountered. As you know, the dc gain of op amps is fairly large. At low frequencies it starts to decrease, or roll off, at a fixed rate. Therefore, we must measure open-loop gain at a very low frequency or at dc. Measurement at dc poses difficult problems because the offset voltage also gets amplified. If the offset voltage is too large, it could cause the output voltage to swing to either its positive or negative saturation level. Therefore, it is better to measure the open-loop gain using ac at some low frequency.

A common circuit used for the measurement of open-loop voltage gain is shown in Fig. 44. The input source is a sine wave at 10 Hz that is applied to the non-inverting input through a resistive divider formed by R_1 and R_2. This resistive divider is designed to reduce and accurately control the input voltage to the circuit. The op amp input voltage is adjusted to some low value such as 100 microvolts.

At first glance it may seem as if the amplifier is not in the open-loop mode because there is a 1 megohm resistor connected from the inverting input to the output and a capacitor of 1,000 microfarads connected from the input to ground. Notice that this test circuit has the same configuration as a non-inverting amplifier circuit: the input signal is applied to the non-inverting input while a feedback network is connected between the output and the inverting input. The only exception here is the use of a capacitor between the input and ground rather than a resistor. This capacitor is an effective impedance with ac signals so it works just as well as a resistor. The value of its reactance at 10 Hz is used with the 1 megohm feedback value to determine the gain. The gain called for by this feedback configuration at 10 Hz is equal to

$$\frac{E_o}{E_i} = \left(1 + \frac{R_f}{X_c}\right)$$

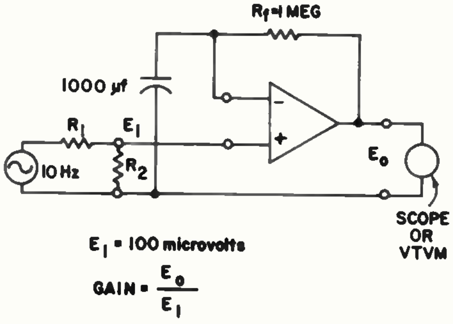

Fig. 44. Open-loop gain measurement.

The capacitive reactance of a 1,000 mfd capacitor at 10 Hz is

$$X_c = \frac{.159}{fC} = \frac{.159}{10 \times 1000 \times 10^{-6}} = \frac{.159}{10^{-2}} =$$

$$.159 \times 10^2 = 15.9 \text{ ohms}$$

Rounding off this value to 16 and using the other values given, we find that this feedback yields a gain of

$$\left(1 + \frac{R_f}{X_c}\right) = \left(1 + \frac{1{,}000{,}000}{16}\right) = 62{,}500$$

or approx. 96 db

In all probability, however, this gain is beyond the capability of the circuit. In other words, even though we have what appears to be closed-loop gain, it is high enough so that the limiting factor will be the open-loop op amp gain. If the op amp has a very large open-loop gain, the values of R_f in Fig. 44 should be further increased. Op amp, open-loop, frequency response is usually flat up to about 100 Hz. Therefore the low-frequency measurement is valid and convenient for measurements with standard instruments.

To measure the gain, we first connect a signal generator, whose output is 10 Hz, to the input and adjust it until the input voltage to the amplifier is 100 microvolts. This can only be done with knowledge of the value of the voltage divider formed by resistors R_1 and R_2. Since 100 microvolts is usually too small to observe directly, you can set the generator output to some more easily measured value and then rely upon the voltage divider ratio to produce an input voltage of 100 microvolts. Next, a high impedance voltmeter or an oscilloscope is connected to the output and the output voltage is measured. The gain is the ratio of the output to input voltage.

If an oscilloscope is used for output measurement, the peak-to-peak value is normally recorded. This must be converted to rms, or the same input voltage units, to obtain the correct value of gain. It is important that the power supply be properly decoupled, or filtered, with large capacitors to ground as close to the amplifier as possible. Should it be required, it is also important to compensate for amplifier oscillation. These precautions should be taken in almost all the measurement circuits we describe.

Gain Stability vs. Temperature. The temperature coefficient, or variation of the gain with temperature, can be measured with the same circuit as Fig. 44. All you have to do is vary the temperature of the amplifier and measure the gain at the various temperatures. A gain vs. temperature curve can then be plotted. The stability factor is a number obtained by dividing the change in gain by the change in temperature. The smaller this number, the better the stability.

Gain Stability vs. Power Supply Changes. The same procedure can be used to measure the variation of gain with changes in power supply voltage. This is often very important because the amplifier specification sheet may call for a gain with a given power supply setting different from the setting being used. To do this measuring, we must know the typical and worst case values for the various power supplies. In general, the gain of the op amp increases as the power supply voltage increases. However, we must be careful to see that the maximum rating of the op amp is not exceeded. The stability factor is a number obtained by dividing the change in gain by the change in power supply voltage setting. The lower this number is, the better the stability.

IMPEDANCE MEASUREMENTS

Open-loop Input Impedance. The open-loop input impedance is measured in a circuit like the one used for the open-loop gain test. The only exception is that a variable resistor (R_3) is placed in series with the input. Refer to Fig. 45. The input voltage is again adjusted to be 100 microvolts at about 10 Hz. With the value of resistor R_3 reduced to zero, the output voltage is measured. The second step is to increase the variable of R_3 until the output drops by 10%. In other words, if the output swings 10 volts peak-to-peak, we increase the value of R_3 until the output drops to 9 volts peak-to-peak. We are decreasing the output by decreasing the value of the input with a voltage divider, formed by the series R_3 and the input impedance to the amplifier. Since the output of the amplifier has dropped 10%, we conclude that the resistance into the input terminal is equal to 9 times the value of R_3 at that setting. All you have to do now is measure the value of R_3 and multiply it by 9. This will give you the input impedance of the amplifier.

The key to understanding this method of measuring the input impedance is to realize that the output voltage of the amplifier drops because of the introduction of variable resistor R_3. When it drops 10%, the relationship between R_3 and the input impedance of the amplifier is 9 to 1.

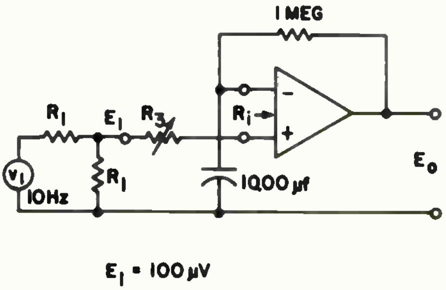

Fig. 45. Measuring input impedance.

In order to use this method, we must have an initial idea of what the input impedance is going to be so we can choose the right magnitude for R_3. For example, this input impedance can be as large as 1,000 megohms in FET input amplifiers. This would mean that the value of the resistor must also be extremely large. Therefore, this method may be impractical for some high input impedance op amps.

Output Impedance. The output impedance measurement is similar to the measurement of the input impedance, but simpler. We'll use the circuit shown in Fig. 46 to illustrate.

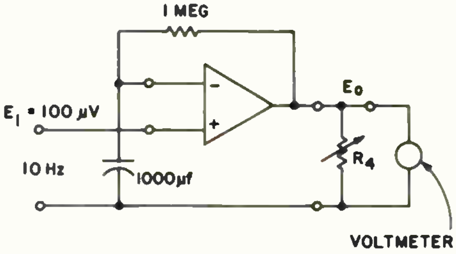

Fig. 46. Measuring output impedance.

We again adjust the input voltage to 100 microvolts but, this time, connect a variable load resistance (R_4) to the output. With the load resistance disconnected, we measure the output voltage. We then connect R_4 to the output and adjust its value until the output voltage drops 10%. For this procedure we must be sure that the output signal is not clipped or otherwise distorted. We are using the output impedance of the amplifier and R_4 as a voltage divider whose output voltage drops as we decrease R_4. When the output voltage drops 10%, the output impedance of the amplifier is equal to the value of the load resistance divided by 9.

INPUT VOLTAGE MEASUREMENTS

Input Offset Voltage. The input offset voltage is very conveniently measured at dc using the circuit shown in Fig. 47. In this circuit we have an amplifier connected in the inverting configuration with an input resistance equal to 100 ohms and a feedback resistance equal to 10K. Therefore, the gain of the circuit is 10K/100 = 100.

With the input shorted to ground, the input to the circuit is equal to the input offset voltage of the amplifier. Since this input offset voltage is usually in the millivolt region, it is difficult to measure; it is best to amplify it and measure the enlarged version at the output. This is what this circuit does. The output voltage, if measured with a suitable voltmeter, will be equal to the input offset voltage multiplied by the gain of the amplifier. What we have done is to use the amplifier to increase its own input voltage by shorting the inputs. Now, if the input voltage is as small as 1 millivolt, it will appear in the output as a more conveniently measured voltage of 100 millivolts.

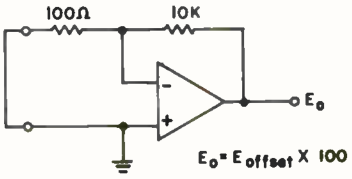

Fig. 47. Input offset voltage measurement.

Input Offset Voltage Drift vs. Temperature. The input voltage drift versus temperature can also be measured in the circuit of Fig. 47. All you have to do is vary the temperature of the amplifier and note the offset voltage change. Then compute the change in offset voltage divided by the change in temperature. The smaller this ratio, the better the matching of V_{be} of the input transistors with temperature.

Input Voltage Drift vs. Supply. The variation of input offset voltage with power supply voltage changes is commonly called the power supply rejection ratio. We measure the input offset voltage with different values of power supply voltages. Then we divide the change in offset voltage by the change in power supply voltage producing that change. The resulting ratio tells us the stability. A low ratio value is desirable. In some cases it is best to vary only one of the two supply voltages at a time.

Input Voltage Drift vs. Time. To measure the input voltage drift versus time, attach a strip chart recorder to the output and let the amplifier run. Then, checking the strip recorder output, we find the maximum output change for the prescribed time.

A strip chart recorder is a special type of voltmeter that records the output voltage in ink on a strip of graph paper. The paper is moved very slowly past the pen that marks a line or curve on it. The position of the pen is determined by the input voltage; the position of the mark on the paper shows the voltage variation with time.

Input Bias Current. The measurement of the input bias current is done best as in Fig. 48A. Rather than measuring the

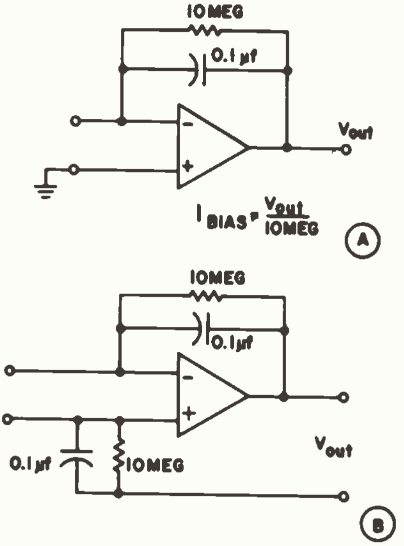

Fig. 48. Input bias current measurement (A) and input offset current measurement (B).

input bias current directly at the input with some form of current meter, we insert a 10 megohm resistor from the input to the output. The other input of the amplifier under test is returned to ground. This circuit takes advantage of the fact that the input bias current, the current that flows into or out of the input terminal, must flow through the 10 megohm resistor and appear as an output voltage. So the approach here is very similar to the one used for the input offset voltage. We convert the current into a fairly large voltage rather than a current of a few nanoamperes, which is very difficult to measure.

To use the circuit shown in Fig. 48A, measure the output voltage (E_o) with a suitable oscilloscope or voltmeter. The input-output current will be equal to the magnitude of the output voltage divided by 10 megohms. The reason for this is that the input bias current is flowing through the 10 megohm resistor. We can use Ohm's Law to determine this current. Let us assume that the output voltage of the amplifier (which we are testing under the conditions of Fig. 48A) equals 1 volt. When we divide this voltage by 1 megohm, we get .1 microampere, or 100 nanoamperes. This is the value of the input bias current flowing into the inverting input.

Using this method we can obtain the current flowing into only one of the input terminals. The current flowing into the other terminal could have a different value. Therefore in order to find the non-inverting input bias current, we must do a similar measurement. To do this we must ground the inverting input previously used and connect the 10 megohm resistor between the other input and ground. Now we obtain another value for input bias, different from the first one. The .1 mfd capacitor across the 10 megohm resistor is used to eliminate any noise or ac signal that could occur.

Input Offset Current. As you know, the average of the two input bias currents is called the input offset current. One way we could measure the input offset current is to individually measure the two input bias currents, add them and divide by two. However, the circuit shown in Fig. 48B shows a more direct way of obtaining the input offset current in one measurement.

We have a balanced input with a 10 megohm resistor and a .1 mfd capacitor connected to both inputs. This way we obtain an output voltage that is proportional to the difference between the two bias currents. To obtain the true input offset current, the value of this output current must be divided by two. In this circuit, the input offset current equals the output voltage divided by 10 megohms, as before.

In order to measure the input bias current drift and input offset current drift with temperature, we place the amplifier in a temperature-controlled environment and note the change in input offset current divided by the change in temperature. That way we get what we call the "temperature coefficient" of the input bias current and of the input offset current.

Often it is important to find the input current drift with power supply voltage changes. Depending upon the amplifier requirements, we vary the power supply output ±10, or 20%, while we monitor the input offset current. We then divide the change in input offset current, caused by the power supply variation, by the change in power supply magnitude. The resulting ratio gives an indication of the stability. A low ratio is most desirable.

FREQUENCY RESPONSE

In order to measure the frequency response, we normally connect the amplifier in the desired configuration. Then we apply a sine wave of varying frequencies to the input while we monitor the output voltage and the gain. However, in order to find the maximum frequency response, it is better to connect the amplifier in the unity gain configuration shown in Fig. 49A.

As we explained before, if feedback is used in an amplifier, the magnitude of the gain decreases and the bandwidth increases. In the extreme case of unity gain, the amplifier frequency response curve extends all the way to the point where it meets the open-loop roll-off curve. This is shown in Fig. 49B. In this figure we show the frequency response for open-loop gain, a gain of 100, and the frequency response of the unity gain amplifier which intersects the axis at the maximum frequency at which the amplifier can be used (F_{max}).

To find the maximum frequency response, we use a signal generator with a variable frequency output. The generator should be set at a fairly low output, e.g., 30 millivolts. The output of the amplifier is monitored with an oscilloscope or voltmeter and the frequency is increased until the output voltage drops 3 db. At this frequency the response will equal the F_{max} of the amplifier. Of course, if some gain is required the procedure will be the

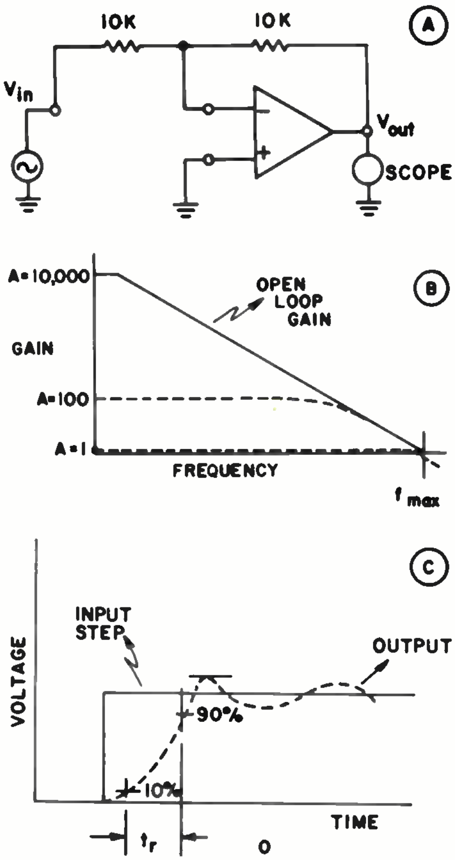

Fig. 49. Frequency response measurement.

same. The frequency response is always taken when the gain drops to 3 db below the low-frequency or dc value. As you can see, this frequency will decrease as the closed-loop gain of the amplifier increases.

Rise Time and Delay Time. The same circuit that was used for the frequency response measurement is also used to find the rise time of the amplifier. However, instead of connecting an input sine wave, we connect a square wave of about 100 millivolts peak-to-peak. We then monitor the output with an oscilloscope. The procedure is to observe the output on an expanded time scale and measure the output rise time from 10% to 90% of its rise. If the square wave input rise is fast compared to the rise time of the amplifier, the rise time of the square wave input can be neglected. For example, if we use a generator with a rise time of 10 nanoseconds and the rise time seen on the oscilloscope is 1 microsecond, the 10 nanoseconds can be neglected.

In Fig. 49C we show a picture of what can be seen on a dual channel oscilloscope. The first signal is the input step, or square wave, which we have shown as an ideal condition with zero rise time. The dashed line is what could be the amplifier output. As we mentioned before, the rise time is measured from the 10% point to the 90% point.

It is also possible that some degree of overshoot will be noticed rather than a smooth signal that simply follows the input. In many cases the overshoot limits must be specified by expressing the amount of overshoot as a percentage of the output voltage. Take the case where the input voltage is 100 millivolts and the output voltage is also 100 millivolts because the circuit is connected with the unity gain configuration. If the output in this situation overshoots to 110 millivolts and then comes back down, the amount of overshoot is 10% (10 millivolts/100 millivolts). In the case of many high-frequency amplifiers, the overshoot can go up to 40%.

The frequency response and rise time characteristics of an op amp are intimately related. In general, amplifiers with very high-frequency response have much faster rise times than amplifiers that have a low-frequency response. The rise time and frequency response are closely related; if one is known, the other can be calculated. The formula F = .35/tr shows this relationship. F is the 3 db down frequency, or the amplifier bandwidth in MHz, where the t_r is the rise time expressed in microseconds. For example, if the rise time is .5 microsecond, the bandwidth, or 3 db cutoff, is .35/.5 = .7 MHz. By turning the formula around (t_r = .35/f), you can calculate the rise time for a given bandwidth.

SUMMARY

In this section we have attempted to describe the procedures for testing, measuring and evaluating some op amp parameters. In many cases such comprehensive tests are not necessary. The most important tests that guarantee op amp performance are:

1. Open-loop gain.
2. Input offset voltage and input offset voltage drift with temperature.
3. Input offset current.
4. Input impedance.

In applications where we are interested in specific characteristics, they must be measured. If we have an op amp that will change very much with time, the variations of gain, offset voltage and current with power supply voltage change become very critical. However, in most applications the parameters given are all that are needed to guarantee good op amp performance.

A lot of these test circuits can be combined with switching arrangements to form a piece of test equipment that can quickly perform all of the op amp tests given here. These automatic test sets for op amps are able to sequence from one test to the other by themselves. By using comparators they provide a light signal of whether all the tests have been passed; if any test was not passed, a red light indicates a no-go condition.

A photograph of one of these units is shown in Fig. 50. The square push buttons are used to select the desired test while the rotary switches select various input parameters. The meter is used for voltage and current measurements. This unit tests integrated circuit op amps that are plugged into the test socket below the push buttons. You are going to study integrated circuits in detail in a later lesson. You will see then how useful this device is in testing integrated circuit op amps.

Courtesy Philbrick/Nexus-Teledyne

Fig. 50. An automatic operational amplifier tester.

SELF-TEST QUESTIONS

(ai) Why is the open-loop gain measurement made at a very low frequency?

(aj) The output rise time of an op amp is 400 nanoseconds (.4 microseconds). What is the 3 db bandwidth?

Answers to Self-Test Questions

(a) True.

(b) False. The gain is the ratio of the feedback to the input resistor.

(c) True.

(d) True.

(e) False.

(f) Gain = $R_f/R_1 = 84K/12K = 7$.

(g) $E_o = -$ gain $\times$ $E_1 = -4(-3.5) = +14$ volts.

(h) High open-loop gain, high input impedance, low output impedance, wide frequency response, direct coupling, low drift, low power consumption, differential inputs.

(i) Gain = $1 + R_f/R_1 = 1 + 120K/30K = 1 + 4 = 5$.

(j) $E_o = R_f/R_1 \ (E_2 - E_1) = 75K/15K \ [-23 - (-16)] = 5(-23 + 16) = 5\ (-7) = -35$ volts.

(k) False.

(l) False. The load is connected between the output and the inverting input.

(m) $k = E_o/E_1 = 9/27 = .333$.

(n) Gain = $1/k = 1/.004 = 250$.

(o) Unmatched emitter-base voltage drop in the differential input transistors is the basic cause of input offset voltage.

(p) Unmatched leakage and Beta in the input transistors cause input offset current.

(q) A high input impedance does not load the driving source.

(r) Rise time is the time it takes the amplifier output to rise from 10% to 90% of its final amplitude in response to a step input.

(s) The power supply voltages determine the output swing limit.

(t) Drift is caused by changes in component characteristics with temperature, time and power supply variations.

(u) No. This circuit can adjust the offset to produce a zero output for zero input, but drift will change the characteristics and make the output above or below zero.

(v) Six db per octave is equivalent to 20 db per decade. 100 Hz to 1 kHz is a decade change so the gain drops by 20 db or from 120 db to 100 db.

(w) Frequency compensation networks insure a 6 db per octave roll-off to prevent oscillation.

(x) High input impedance can be obtained by using FET input transistors, the Darlington connection or super-high Beta transistors at low current levels.

(y) A booster amplifier is used with an op amp to permit it to develop its normal output voltage across a low resistance load. It is a power amplifier.

(z) The internal self-bias, due to the depletion layer, causes crossover distortion.

(aa) $E_o = -\left[E_1(R_f/R_1) + E_2(R_f/R_2) + E_3(R_f/R_3)\right]$

$E_o = -\left[-10(20K/10K) + 6(20K/5K) + 8(20K/2K)\right]$

$E_o = -\left[-10(2) + 6(4) + 8(10)\right]$

$E_o = -(-20 + 24 + 80) = -84$.

(ab) True.

(ac) True.

(ad) True. Changing the feedback capacity varies the gain so the rate of output voltage change can be controlled.

(ae) False. The op amp integrator does invert.

(af) Gain = 1/R-C = 1/(100K X 1 mfd) equals
$1/(100{,}000 \times 1 \times 10^{-6}) =$
$1/(10^5 \times 10^{-6}) =$
$1/10^{-1} = 1/.1 = 10.$

(ag) $E_o = -1/R\text{-}C \cdot E_{in} \cdot t = -10 (-.3)(7) = 21$ volts.

(ah) True.

(ai) Since the gain begins to roll off at a very low frequency, to obtain a measurement of the maximum open-loop gain, the test should be performed at dc or some low frequency before this roll-off occurs.

(aj) Bandwidth $f = .35/t_r = .35/.4 =$ .875 MHz or 875 kHz.

Lesson Questions

Be sure to number your Answer Sheet K309.

Place your Student Number on every Answer Sheet.

Most students want to know their grades as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of lessons before new ones can reach you.

1. What three transistor characteristics affect input offset voltage and current?

2. What two external conditions are most responsible for changes in op amp characteristics?

3. A two-input op amp summer has input resistors R_1 = 50K, R_2 = 40K to which are applied input voltages of E_1 = −30 volts and E_2 = +40 volts. The feedback resistor R_f is 200K. What are the output voltage amplitude and polarity?

4. Name two ways of getting high input impedance in an op amp.

5. An input voltage of −2.3 volts is applied to an op amp follower. What is the output voltage?

6. A triangular waveform is applied to a comparator whose reference input is grounded. The output signal will be:

   (a) A triangular wave
   (b) A sine wave
   (c) A square wave
   (d) A fixed dc voltage

7. The output saturation limit on an op amp integrator is ±50 volts. The integrator gain is 5, the input voltage is +2 and the circuit integrates for 4 seconds. Is the output in saturation?

8. The 10% to 90% output rise time of an op amp is .08 microseconds. What is the upper 3 db down bandwidth?

9. As the closed-loop gain of an op amp circuit increases, the bandwidth

   (a) increases
   (b) decreases

10. Name five mathematical operations that an op amp can perform.

3-25-76

$E_o \quad R_c\,(E_i)(T)$

$E_o \quad 5(+2)(4)$

$E_o = 40v$

$F = \frac{1.3}{tn}$

$1 \quad \frac{22}{.05} = 4.375$ n Hz

COMPETITION

When a competitor opens a shop in your neighborhood, your first reactions are probably the same as those of most people – you feel that he is "cutting in" on your trade and that, by fair or foul means, he may run you out of business. However, there is another view to take of this problem.

First, forget your fears! A mind frozen by mistrust and hate is incapable of reasoning; it will lead you to the very downfall you fear. Face the facts: someone else is in the same business, so you must make your services so much better than his that you get your share of the work.

Welcome the competition as a spur – something to force you to your best efforts – something to make you become more careful, more efficient, more alert. You will find that honest competition adds enjoyment to your work.

And, another thing, force your competitor to rise to your level to survive – don't stoop to his. Do your best work and you'll find that your fears were not justified – there is plenty of business for the man who can deliver the goods!

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ACHIEVEMENT THROUGH ELECTRONICS

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INTRODUCING YOU TO ELECTRONICS

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INTRODUCING YOU
TO ELECTRONICS

B101

STUDY SCHEDULE

By dividing your study into the steps given below, you can get the most out of this part of your NRI Course in the shortest possible time. Check off each step when you finish it.

☒ 1. **Introduction** .... **Pages 1 - 4**
This section gives you a glimpse of the opportunities in store for you, and also some helpful suggestions on how to study.

☒ 2. **Electricity** .... **Pages 5 - 12**
You get a basic idea of what electricity is.

☒ 3. **Current Flow** .... **Pages 13 - 17**
You learn how current is made to flow in a circuit, and the relationship between current, voltage and resistance.

☐ 4. **Magnetism** .... **Pages 18 - 24**
You learn about the importance of magnetism in electronics.

☐ 5. **Electronic Components** .... **Pages 25 - 37**
We look at a number of basic parts; conductors, insulators, batteries, coils, transformers, resistors, vacuum tubes and transistors.

☐ 6. **Answers to Self-Test Questions** .... **Pages 38 - 39**

☐ 7. **Answer the Lesson Questions.**

☐ 8. **Start Studying the Next Lesson.**

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INTRODUCING YOU TO ELECTRONICS

Deciding to study the NRI course is one of the wisest decisions of your life. Why? Because this course has been planned and written from beginning to end especially for men who must do their studying at home, usually after their regular day's work. Each of NRI's bite size lessons has been programmed into small sections. Most of these sections can be mastered with little over an hour's diligent study.

The amount of education you now have is of less importance than an unswerving ambition to succeed. The first lesson starts right at the beginning assuming that you know nothing about electronics, and prepares you for the more advanced second lesson. If you will make a firm resolution now to work on your course regularly, you can be assured of success. The rewards that can be yours by satisfactorily completing your course are within your grasp. You've taken the first step by enrolling, now the next step is to set up a study schedule, and then stick to that study schedule at all costs.

Since in the second book, and in each of the following books that you will study, you will be building on what you have learned in previous books, it is important for you to understand each new idea as it is presented before going on to the next subject. Do not make the mistake of skipping over a section that you do not at first understand. Usually if any section of a lesson at first seems difficult, you will be able to understand it completely by rereading it several times. If after you have carefully studied a section of a lesson, you find there are still some points puzzling you, take advantage of the NRI Consultation Service to ask for extra help. Try to be as specific as possible about exactly what is not clear to you -- we will be glad to assist you; we are here to help you.

The surest way to succeed is to be determined to succeed. Make a sincere promise to yourself right now, that you are going to complete your NRI course and succeed in electronics.

OPPORTUNITIES

Let us look at a few of the opportunities that are available to the qualified technician. As an NRI graduate you will be in a position to choose your opportunity, instead of waiting for it to come to you.

In radio, for instance, there are hundreds of different job opportunities in entertainment broadcasting alone. You might think that television has eliminated the opportunities in this field of radio. The actual facts are that almost every week new radio stations are licensed by the FCC and that the annual radio receiver production in this country is close to 10,000,000 receivers.

Television has not eliminated opportunities in the radio field; instead it has created new opportunities of its own. The demand for broadcast technicians and television servicemen has never been fully satisfied since television first swept across the country. Now color television is here, and it is creating still greater demands for trained men. You can be one of them.

Another fact that people fail to realize is that there are many opportunities outside the entertainment broadcasting field. There are thousands of fascinating well-paid jobs for men in communications systems on land, on sea, and in the air. Fire and police departments, telephone companies, power companies, gas companies, railroads, and airlines are only a few of the many organizations using radio communications equipment. The use of radio in industrial communications is in fact increasing so fast that finding frequency assignments for all the new stations is becoming a serious problem.

Electronic equipment is also becoming more and more important in industry. Electronics in industry represents a tremendous new field, the surface of which has just been scratched. Electronic equipment is used to count finished components coming off assembly lines, it is used to inspect manufactured parts, it is used to control precision machines, automatically making possible the high-speed production of items that could formerly be made only manually by highly skilled operators. Electronics is used in oil refineries, in the manufacturing and quality-control of new cars, in the new plastics industry and in many other fields, too numerous to mention. As a matter of fact, there is hardly an industrial process in which electronics cannot be put to use advantageously. Here is a field of unlimited opportunities; a field that is just developing.

From the preceding list of opportunities you might think that this is an industry already fully developed. Actually we have barely scratched the surface. You are going to see breath-taking new developments which far outshadow even the miracle of color television. Because your NRI training is built upon a sound foundation, you will be prepared for the undreamed-of jobs that will soon be created by new developments. You will not only learn about equipment in use today, but you will also learn the fundamental ideas in back of the operation of tomorrow's equipment. Once you understand this basic theory, you will be able to understand new developments as they come along. You will understand how they work, because you will know the fundamentals. New electronic equipment will not use new circuits, it will use the basic circuits you will be studying, but in new ways.

HOW TO STUDY

Naturally, you want to complete your course and become an expert technician as quickly as possible. To help you do this, here are a few suggestions on how to study.

A Study Schedule.

The first suggestion is that you plan a study schedule. Decide how many hours you'll study each week. Then decide on which days you will be able to work on your course. Finally, decide the time during the day or evening that will be best for studying.

How Often to Study.

Space your study periods close together. The ideal arrangement is to devote some time to your course each day. If you can't spare one or two hours, study for 45 minutes, half an hour, or whatever you can spare.

Regular study is the key to learning effectively. You can learn and remember much more from studying 30 minutes daily than from longer sessions spaced several days apart. Studying daily, or every other day, keeps the instruction fresh in your mind. If three or four days pass between study periods, you may forget most of what you learned from your last session. It's hard to pick up where you left off, and you often have to do a lot of "back-tracking" to refresh your memory.

Take a Break.

Unless you're accustomed to studying regularly, you may find that you tire easily. This isn't unusual. It will take time for you to get the "study habit".

In the beginning, make your study periods short and break them up with periods of rest. After you've completed several lessons, you will be able to study longer without getting tired.

Be Fair to Yourself.

Most of us have asked for that second slice of apple pie only to discover we are too full to handle it. An over-ambitious study schedule can be like that second slice of pie. Be sure your study schedule is reasonable, one that you will have no trouble following. This schedule need not deprive you of time for other activities. A well planned schedule will see to it that each activity gets its fair share of your attention.

If possible, have a regular place to study, and get used to going to the same place each time you study. Naturally, this place should be relatively free of distracting noises. If the noise around you can't be controlled, consider going to a Public Library. Libraries are quiet and have an ideal study atmosphere.

When you sit down to study, be sure to have everything you need. Then you won't have to stop in the middle of a lesson to get a pencil, paper etc. Keep these materials near your place of study at all times so that once you sit down, you can go right to work.

Here are some suggestions to help you study your lesson texts systematically. These suggestions are the result of years of experience with well over 600,000 students and will enable you to learn effectively.

Survey the Lesson.

Begin each new lesson with a survey. First, read the Study Schedule to get a general idea of the subjects and their order of presentation. Next, thumb through the lesson and look at the different main headings. The main headings are the same as each step in the Study Schedule.

Now carry the survey further. Look at the smaller headings under each main heading to get a more detailed idea of what the lesson covers. In fact, you should glance at the first two or three sentences under each heading.

The survey acquaints you with the lesson. When you begin a thorough study, you will know what to expect.

Read and Recite.

After the survey, you are ready to study the lesson. Remember, the text is full of facts and explanations. To absorb them, you should read every sentence carefully, turning over in your mind what it says and means.

Stop periodically and try to recall what you've read. Actually recite to yourself the main headings and the important ideas under each. Then check back to see whether you've covered everything. If you've left something out, restudy those points and again try to repeat them to yourself.

Answering the Test Questions.

On the last page of each lesson are ten questions covering subjects in the lesson text.

You'll probably find many of the questions easy to answer. Some will require a good deal of thought. A few may seem difficult but will help you develop the ability to work out problems you'll encounter in the field.

If you come to a question you can't answer, find that part of the lesson where the subject is covered. Reread that portion carefully, fixing the answer to the question firmly in mind. Then write out the answer in your own words.

You will find it helpful to review periodically. A good system is to review completed lessons at about the same rate you study new lessons.

For example, when you finish six lessons, go over the first two again. When you finish your next new lesson, review the third and fourth lessons. After your review catches up to your new lessons, start the review over again. Naturally, when you review, you will not have to be as thorough as when you study the lesson. However, just skimming through the lesson you are reviewing will help recall the important points in that lesson.

Your lessons contain a series of self-test questions which are related to the major topics of each text. You should try to answer each question, in writing, as you come to it in your studies. Before continuing, check your answer against the "Answers to Self-Test Questions" on pages 38 and 39. If you have answered the questions correctly, go on to the next section. If any of your answers are incorrect, review the topic just covered.

These Self-Test Questions are for your own use so you can see how well you understand the material. Do NOT Send the Answers to the Self-Test Questions to NRI for Grading. This will only slow down your instructor.

Now you are ready to go -- ready to start your study of electronics. At first we will study a few basic ideas and then we will use these ideas in building up some simple circuits. Make sure you fully understand the ideas and circuits as they are presented. Even the most complex electronic equipment is made up of nothing more than a large number of the simple circuits that you will study in your early lessons.

Electricity

Electricity and magnetism play an important part in the operation of all electronic equipment. But what is electricity? What is magnetism? If you learn the answers to these two questions once and for all now, you will have the foundation for everything else you will study and work with in your electronics career. Let us take up electricity first.

WHAT ELECTRICITY IS

We will start our discussion of what electricity is by describing a few simple experiments that were performed by scientists many years ago. These experiments helped lead to the understanding of electricity that we have today. You do not have to perform these experiments. We are describing them only to help you understand electricity.

If two small glass balls are suspended by threads as shown in Fig. 1, the weight of the glass balls will cause them to hang straight down as shown. Now if we take a piece of silk cloth and rub the balls with the cloth and then suspend them, instead of hanging straight down as they did before, the balls will tend to swing out as shown in Fig. 2 as though some force were pushing them apart.

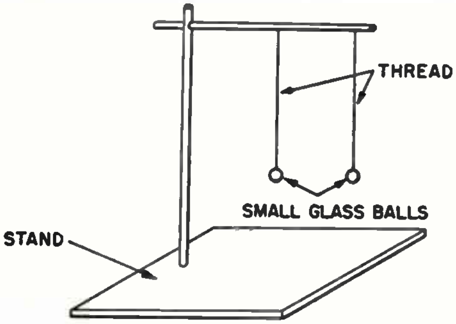

Fig. 1. Two small glass balls suspended by threads will hang vertically because of the weight of the balls.

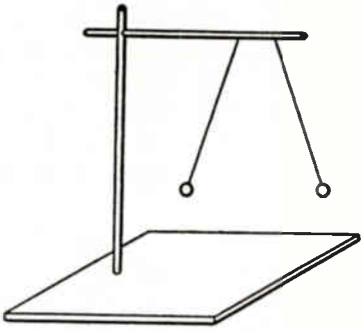

Fig. 2. Two glass balls that have been rubbed with a silk cloth move apart.

Actually, there must be some force pushing them apart; rubbing the balls with the silk cloth has produced the force.

The same experiment can be performed using two small hard-rubber balls. Again, before the balls have been rubbed with the silk cloth they will hang vertically, but once they have been rubbed with the silk cloth they will push apart. Again rubbing the small balls with the silk cloth has produced a force which pushes the balls apart.

There are two important points illustrated by these experiments. First, rubbing the balls with the silk cloth produced a force that pushed the balls apart. We call this force a "charge". The act of producing this force is called "charging". We say that the balls are "charged."

Second, let us consider what happened when we rubbed the glass balls with the silk cloth. When we rubbed the two balls, we charged them. Since both balls were charged in the same way, it is logical to assume that we have placed the same kind of a charge on the two balls. But the two balls pushed each other apart. We had similar results when we charged the two rubber balls. They also repelled each other. From these experiments we can conclude that if two objects are charged with the same kind of a charge, they will repel each other. This is a basic electrical law, and it is usually stated:

like charges repel.

Now, if the same experiment is performed using one small glass ball and one small rubber ball, we would observe an entirely different effect. When the balls are rubbed with the silk and then suspended, instead of moving apart, the two balls would move toward each other as shown in Fig. 3. If they are placed close enough together, they will move toward each other until they touch. Once the two balls touch each other, they will begin to move apart to hang straight down. They will probably swing past the straight-down point and then swing back together and touch again. This cycle may be repeated several times until eventually the balls will hang straight down as they would if they had not been charged in the first place. Now let us see what conclusions we can draw from this experiment.

We have seen that rubbing the two balls with the silk cloth charged them as before. This we know is true because a force was produced on the two balls, otherwise they would simply hang straight down. We also know that the forces produced on the two balls were such that the balls did not repel each other, at least at first, because the two balls moved together and touched. Since we have seen from the previous experiments that like charges repel, these charges must have been unlike. In other words, there must be a different kind of charge on the glass ball from the one on the rubber.

These simple experiments lead us to a fundamental important rule,

"like charges repel;
unlike charges attract."

Remember this rule, it is important. You will use it throughout your entire career in electronics. You will soon use this simple rule to help explain the operation of many electronic devices.

Now let us proceed with our study of electricity to see if we can explain more fully what happened in the experiments we have just described. To do this we must study the electron theory.

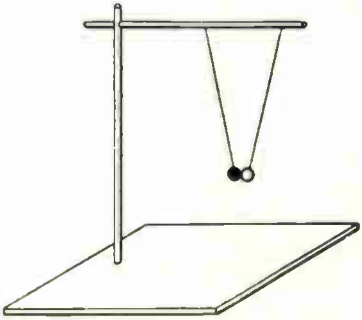

Fig. 3. The charged glass and rubber balls will move together and touch each other.

THE ELECTRON THEORY

Everything on this earth is made up of tiny particles. You can see for yourself that the earth is not one solid piece of material, it is made up of tiny particles of sand and stone and rock. Even the smallest grain of sand is itself made up of millions of still smaller particles, so small that they cannot be seen even with the most powerful microscope.

The smallest particle of a substance that retains the original properties of the substance is called an "atom." All atoms of a given substance are alike. In other words, the smallest particle of a piece of copper that still is and resembles copper is called an atom. These atoms are so small that a piece of copper the size of the head of a pin would contain millions of atoms.

But the atom is not the smallest particle, the atom itself is made up of still smaller particles. Scientists have identified a number of different particles from which the atom is made. However, we are interested in only two of these particles, the nucleus* and the electron. We are more interested in the electron than we are in the nucleus.

The nucleus is the center of the atom. Travelling around the nucleus in elliptical paths (a somewhat circular path that has been squashed, like an egg or football) will be one or more electrons. The number of electrons will be different for atoms of different elements.

The nucleus of an atom has a positive charge. The simplest atom is the hydrogen atom and the nucleus of this atom has one positive charge. Travelling around this nucleus in an elliptical path is one electron which has a negative charge. The negative charge on the electron exactly balances the positive charge on the nucleus so that electrically the atom is neutral. The most complex atom found in nature is the uranium atom. The nucleus of the uranium atom has 92 positive charges and travelling around the nucleus of this atom are 92 electrons which will exactly balance the 92 charges on the nucleus, so that the net electrical charge on the atom is zero.

Between the simplest atom, which is the hydrogen atom, and the most complex atom are 90 other materials. They range from the helium atom which has two positive charges on the nucleus and two electrons travelling around it up to the protactinium atom which has 91 charges on the nucleus and 91 electrons travelling around it.

In their natural state the electrons travelling around the nucleus of an atom exactly balance the positive charges on the nucleus. However, under some circumstances an atom might loose one of its electrons. When this happens, the electron, which carries a negative electrical charge, moves off into space or over to a nearby atom. Meanwhile, the atom which has lost the electron now does not have enough electrons to completely balance the positive charge on the nucleus. As a result, the atom has a positive charge.

Under some circumstances the opposite might happen, and an atom might pick up an extra electron.

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* To be strictly correct we should not call the nucleus a particle, because it is made up of smaller particles. However, for our purposes we can consider the nucleus as one particle.

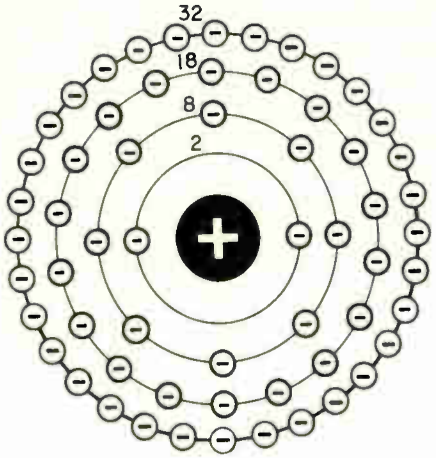


Fig. 4. The maximum number of electrons there can be in each of the first four rings of any atom.

When this happens the atom has more electrons than it needs to completely neutralize the charge on the nucleus. As a result, the atom will have a negative charge.

The electrons around the nucleus of an atom travel around it in rings. There is a maximum number of electrons that can be in each ring. In Fig. 4 we have shown the maximum number of electrons that can be in each of the first four rings surrounding the nucleus of an atom. As the atoms go from hydrogen, the simplest atom, to uranium, the most complex atom, the electrons fill the inner rings first. For example, the hydrogen atom shown in Fig. 5A has one electron traveling around the nucleus. The helium atom shown in Fig. 5B has the first ring filled with two electrons travelling around the nucleus. The lithium atom has three electrons as in Fig. 5C, two electrons fill the first ring and the third electron appears in the second ring. Subsequent elements will have electrons in the second ring until a maximum of eight electrons is reached in this ring. The next element will have two electrons in the first ring, eight in the second and the eleventh electron in the third ring.

When the outer ring of electrons in an atom is filled, the atom is very stable electrically and chemically. It is almost impossible to get an electron to move out of the atom or to force another electron into the atom. On the other hand, if the outer ring has all the electrons it can hold except one, it is very easy to force an electron into that outer ring to fill the ring. By contrast, if the outer ring has only one electron in it, that electron is not held very closely to the atom and therefore it can easily move out of its position into space

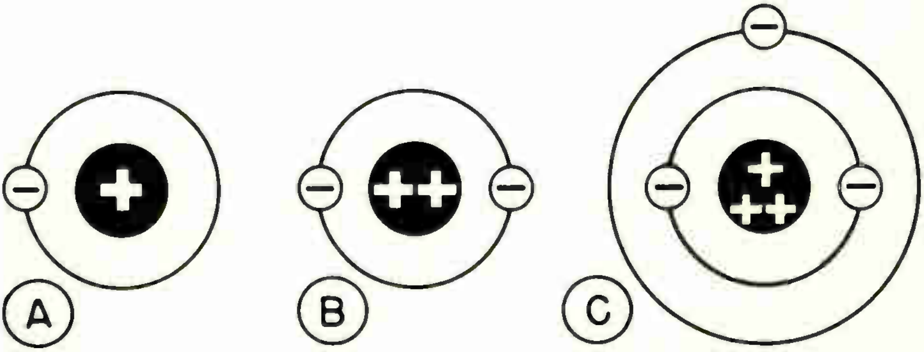


Fig. 5. The hydrogen atom is shown at A, the helium atom at B, and the lithium atom at C.

or to another atom.

The copper atom is an excellent example of an atom with one electron in its outer ring. The positive charge on the nucleus of the copper atom is 29 as shown in Fig. 6. The first three rings of the atom are filled, they hold all the electrons they can. However, the 29th electron required to neutralize the charge on the nucleus is in the fourth ring by itself. This electron is not held very closely to the nucleus. As a result, it can move easily from one atom to another. This is the reason why copper wire is so widely used in electronic equipment and in electric power distribution.

If we apply some external force to a copper atom, we can easily knock the outermost electron loose and it might move to an outer ring of a nearby atom. This atom will then have two electrons in the fourth ring. It then has one more electron than it needs to neutralize the charge on the nucleus. The tendency is for this atom to get rid of this extra charge as quickly as possible. Either the new electron that moved into the fourth ring will be forced out of this ring, or the original electron in the fourth ring will move out. In any case, whichever of the two electrons leaves this fourth ring will move over to a nearby atom, and it in turn will upset the balance of this atom and either move on itself, or force the electron in the outer ring of this atom out.

Now if you will remember when we rubbed the two glass balls and the two rubber balls with a silk cloth and placed like charges on them they repelled each other. Electrons have a negative electrical charge. All electrons have exactly the same charge. Since the charges on electrons are like charges they tend to repel each other.

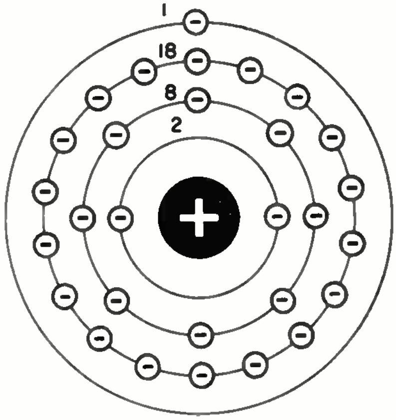


Fig. 6. The nucleus of the copper atom has a positive charge of 29. Around the nucleus there are normally 29 electrons arranged as shown above.

In a piece of copper there will be millions of atoms. Each of these atoms will have a nucleus that has a positive charge of 29 on it and around it 29 electrons that neutralize this positive charge. The electrons are held in the atom by the positive charge on the nucleus which attracts them. At the same time the electrons are repelling other electrons in the atom and electrons in nearby atoms. There is more or less a condition where there is a balance between the nucleus holding or attracting its electrons and at the same time the electrons repelling or pushing away other electrons.

If we take a piece of copper wire and connect something to it that will try to pull electrons from one end of the wire and push them into the other end we will set up an instantaneous chain reaction along that wire. The instant an electron starts to move out of the fourth ring of one of the copper atoms the negative charge on

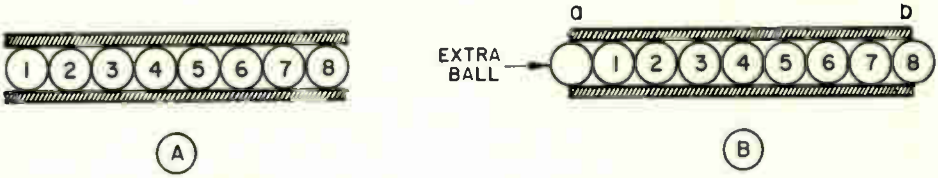


Fig. 7. The hollow tube shown at A is full of ping pong balls. When an extra ball is pushed into end a at B, the effect is to push all the balls at once and a ball starts to to fall out at end b.

that electron will push an electron out of the fourth ring of a nearby atom. At the same instant, it in turn will start pushing an electron out of the fourth ring of an atom adjacent to it. This will happen all the way along the wire so that at the instant an electron starts moving at one end of the copper another electron will start moving at the other end. The motion of the electrons will be the same all through the length of the wire.

You might get a better idea of what is happening if you took a hollow tube such as shown in Fig. 7A and filled it with ping pong balls so that the balls are all touching each other. The minute you start to force an extra ball into the one end, a, all the balls in the tube start to move and a ball starts to fall out of the end b as shown in Fig. 7B. The movement is instantaneous through the entire length of the tube.

The same situation exists when you start an electron moving at end a of the wire shown in Fig. 8. Although the electrons are not touching each other there is a force between them as shown, so that this force causes electrons all down the wire to start to move at the same instant. If you were to apply a greater force so that two electrons started moving at end, a, of the wire as shown in Fig. 9A, this force would cause two electrons to start moving all the way down the wire as shown. Similarly if you increase the force still further and start three electrons moving at end, a, as shown in Fig. 9B, then you have this chain reaction of three moving the entire length of the wire. The motion of electrons will be the same throughout the length of the wire.

The movement of electrons along the wire is called current flow. This is what an electric current is. We will go into this in detail in the next section of this lesson. However, be-

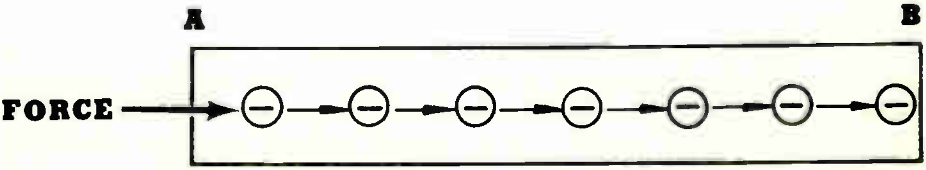


Fig. 8. When force is applied at end A of wire and an electron is pushed towards B, there is an instantaneous reaction all along the length of wire pushing a line of electrons towards B.

fore going to the next section let us explain the action of the charged rubber and glass balls. When the glass ball is rubbed with the silk cloth, the friction of rubbing the ball removes some of the electrons from the ball. Once the electrons have been removed, there are not enough electrons left to completely neutralize the charges on the nuclei of the atoms. Therefore the glass balls will have a positive charge on them.

When we rub the rubber balls, the rubber balls take electrons from the silk cloth so they will have more electrons than are needed to completely neutralize the positive charges on the nuclei of the atoms. Therefore the rubber balls will have a negative charge on them.

Since the two similarly charged glass balls repelled each other and likewise the two charged rubber balls repelled each other, we assumed that like charges repelled. Indeed, two positive charges will repel each other, and two negative charges will repel each other.

When we charge one glass ball and one rubber ball and suspend them near each other, they will be attracted because they have unlike charges; one is charged positive and the other is charged negative and unlike charges attract. When they move together and touch, some of the extra electrons on the rubber ball will leave the rubber ball and move over to the glass ball and partly make up for the shortage of electrons on the glass ball. When this happens, the balls may swing apart, but the charges will not be completely neutralized, so the balls will swing back together again and a few more electrons will move from the rubber ball over to the glass ball. This swinging back and forth will continue until enough electrons have moved from the rubber ball to the glass ball to reduce the force of attraction between the two balls until it is no longer strong enough to cause the balls to swing together.

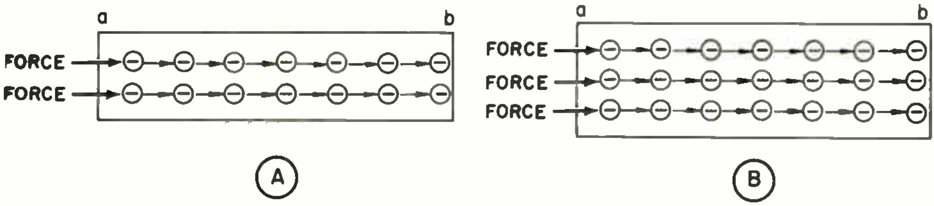


Fig. 9. Number of electrons set in motion along a wire depends on the force applied.

SUMMARY

We have covered a great deal of material in this section, and chances are you will not be able to remember all of it. We do not expect you to remember all of the details, but you should remember the important points such as:

1. Like electric charges repel, and unlike electric charges attract.
2. All material is made up of extremely small particles called atoms.
3. All the atoms of a given substance are identical.

4. Atoms are made up of a nucleus in the center, which has a positive charge, and a number of electrons, which have negative charges. Normally the atom will have enough electrons to exactly neutralize the charge on the nucleus.
5. The electrons arrange themselves in rings around the nucleus of the atom. There is a maximum number of electrons that can be in each ring.
6. In some atoms, such as the copper atom, an electron can be easily displaced.

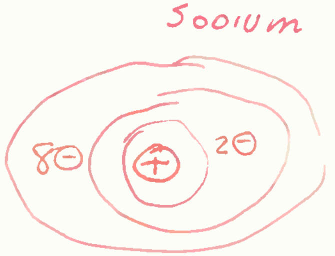
SELF-TEST QUESTIONS

Before going on with the next section of this lesson be sure to answer the following self-test questions. Write out the answer to each question carefully. After you have answered all of the questions, check your answers with those on pages 38 and 39. We do not expect you to give the same answer, but be sure that you understand the point brought out by the question before going on to the next section. Remember, do NOT send your answers to the Self-Test Questions to NRI for grading.

(a) State the law of charges.
(b) What is an atom?
(c) Which two parts of the atom are we interested in?
(d) Which part of the atom has a positive charge? Which part has a negative charge?
(e) If the copper atom which normally has 29 electrons loses one of its electrons, what kind of a charge does the atom have?
(f) Why do electrons in adjacent atoms repel each other?

If you can answer the preceding self-test questions you can be sure that you understand the important points covered in the preceding section of this lesson. However, before going on, here is a real tough question for you to think about. Don't spend more than five or ten minutes thinking about it, but try to answer it because this will stick in your mind and help you to remember some of these important points later.

(g) One atom has ten electrons and another atom has eleven electrons. Which of the two atoms would you expect would most readily give up an electron?



1⊖ the 11-electron atom

Current Flow

In the preceding section you have seen how an electron being knocked out of its atom forces additional electrons out of their atoms and sets them in motion. We have also pointed out that if we apply some force to push the electrons at one end of a wire and another force to pull the electrons from the other end we can start an instantaneous motion of electrons along the wire with the electrons moving from one end towards the other.

A device that is capable of doing this is a flashlight cell. A flashlight cell, by means of the chemical action that occurs inside it, will push electrons from one terminal and pull them into the other. If we connect a wire between the two terminals of a flashlight cell, electrons will immediately be set in motion through the wire and through the cell as shown in Fig. 10. Electrons will be moving from the one terminal of the flashlight cell through the wire and back to the other terminal of the cell, and through the cell back towards the terminal from which they started. This is called an electric circuit.

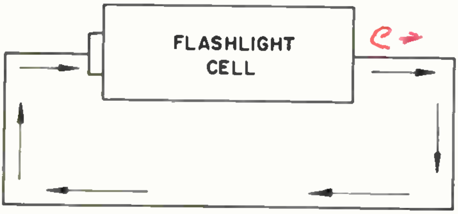


Fig. 10. A wire connected between the two terminals of a flashlight cell provides an electric circuit through which electrons can flow.

Electrons will continue to follow this circular path until the path or circuit is broken by disconnecting the wire from one terminal of the cell or until the chemical action of the cell is exhausted.

Notice that there must be a complete path for the electrons to travel. An electron leaving one terminal of the cell must be able to travel through a complete circuit, through the wire, through the cell and back to the terminal from which it left. If you simply connect a wire to one terminal of the cell, nothing will happen.

A flashlight cell has two terminals. One terminal is a small round terminal in the center of one end of the cell. This is the positive of the cell. The other end of the cell is the negative terminal of the cell. Now, can you tell from which terminal the electrons are going to leave the flashlight cell? Remember the experiment with the glass balls. When we charged the glass balls we placed a like charge on the two balls and they pushed each other apart. Now an electron has a negative or minus charge. Which terminal is going to push electrons away, and which terminal will attract them? The answer to these two questions is just what you might expect from the law of charges. We said that like charges repel, and therefore the negative terminal of the battery will push the electrons out of the battery. The positive terminal of the cell will attract the electrons, because it has the opposite charge on it.

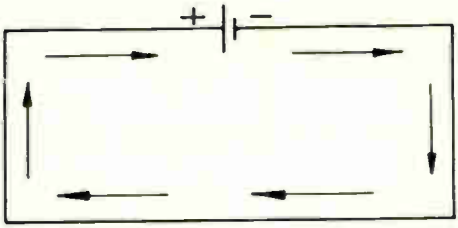


Fig. 11. The schematic diagram of a simple circuit.

In Fig. 11 we have repeated the circuit shown in Fig. 10; however, this time we have used the symbol that is used in electronics to identify a single cell such as a flashlight cell. Notice that we have used one short line and one longer line to represent the cell. The short line identifies the negative terminal of the flashlight cell and the long line the positive terminal. We have also marked the terminals with - and + signs so that there will not be any confusion. Remember the symbol used for the cell, you will see it many times in your electronics career.

Symbols like these are used on all electronic diagrams to indicate the various parts. There is a different symbol for each part. Using a simple symbol instead of trying to show the actual part makes the diagram much easier to understand. These diagrams using symbols are called "schematic" diagrams and the individual symbols, schematic symbols. We will teach you each symbol as you come to it so you will not have to learn a lot of them at once.

In the circuits shown in Fig. 10 and 11, the electrons leaving the negative terminal of the battery simply flow through the wire back to the positive terminal - they are not doing anything useful. Usually we will have some other device connected in the circuit so that the electrons flowing in the circuit will do something useful. For example, in a flashlight we have the flashlight bulb connected between the two terminals of the flashlight cell. The flashlight bulb is simply made of a piece of wire, usually some very hard wire such as a tungsten wire which is placed inside of the glass envelope from which all the air has been evacuated. When we connect the flashlight cell in the circuit such as shown in Fig. 12, the electrons will be set in motion instantaneously throughout the entire circuit as before. However, the movement of electrons through the tungsten wire produces a great deal of heat in the wire; in fact the wire gets so hot that it reaches "white" heat and gives off light. Here we have put the movement of electrons to work, and have used it to produce light. Circuits such as shown in Figs. 10 and 11 where the electrons simply travel from one terminal of the battery to the other are usually avoided. Sometimes they occur accidentally due to a parts failure and they are then referred to as short circuits. You will learn more about this in later lessons.

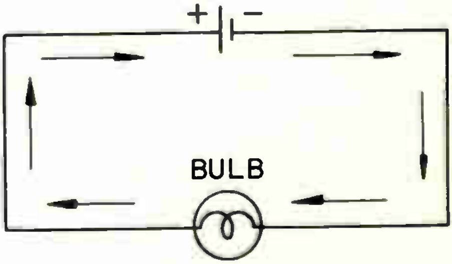


Fig. 12. A simple circuit showing a bulb connected across a flashlight cell.

THE AMPERE

The movement of electrons through an electric circuit is called an electric current. The strength of the current depends on the number of electrons in motion at any point in the circuit. As we pointed out previously, the number of electrons in motion will be the same at all points in the circuit. In the circuits shown in Figs. 11 and 12 the number of electrons leaving the negative terminal of the battery at a given time will be exactly equal to the number of electrons flowing through the flashlight bulb at the same time and also equal to the number of electrons reaching the positive terminal of the battery.

The number of electrons set in motion depends upon the force applied to the circuit, and also on the material used in the circuit. Some materials give up one or two electrons more readily than others, and as a result it is easier for the electrons to move through circuits made of these materials than in circuits made up of other materials that will not give up their electrons so easily.

We must have some way of knowing how much current there is flowing in a circuit. A movement of one or two electrons past a point in a circuit in a period of one second represents an extremely small current, so small in fact that it would be of no useful value. Before a current can be useful, there must be a tremendous number of electrons moving past each point in the circuit. It would be impractical to try to count the number of electrons, so instead, a unit of current called the "ampere" has been devised. The ampere represents a useful number of electrons flowing past a given point in the circuit per second. The actual number of electrons that will pass the point is unimportant. However, a standard ampere has been set up, and all current measurements are made in relationship to this standard ampere. If the number of electrons flowing in the circuit is twice the number represented by one ampere, then the current flowing in the circuit is two amperes. If it is ten times the standard ampere, the current flowing is ten amperes. The word ampere is used so often in electronics that we abbreviate it "amp". To make it plural, we simply add an "s", for example 10 amperes is written 10 amps.

THE VOLT

When we were discussing the ampere, we said that the amount of current that will flow in a circuit depends upon the force applied to the circuit. We should have some means of measuring this force. The force is called the "electromotive force", or "voltage", and it is measured in volts. Often you will see electromotive force abbreviated "emf".

You do not have to be concerned about exactly how much force there is in one volt; the important thing is to know that the number of volts indicates the amount of force applied to the circuit, and the higher the voltage, the more force is being applied to the circuit. In other words, two volts represents twice as much force as one volt. Ten volts represents ten times as much force as one volt.

By way of interest you might like to know that the voltage of a conventional flashlight cell is approximately one and a half or 1.5 volts. The storage batteries used in modern automobiles are made up of six cells connected so that the voltage of the six cells adds. Each cell has a voltage of about 2 volts so that the total battery voltage is 12 volts. Older automobiles may have 3 cell storage batteries - the voltage of these cells is 6 volts. Electric light bulbs and most appliances in homes are designed to operate on a voltage of about 120 volts.

THE OHM

The amount of current that will flow in a circuit depends on one other thing besides the force applied to the circuit. This is how readily the material will give up electrons and let them move in the circuit. Some materials will give up electrons quite readily and let them move through the circuit with little or no opposition. However, other materials will not give up electrons so readily, and may offer considerable opposition to the flow of current. This opposition to current flow is called "resistance". The resistance of a material depends upon how readily it will allow electrons to move through it. Resistance is measured in "ohms". Again, you need not know the exact definition of a standard ohm, the important thing to know is that resistance is the opposition to current flow in a circuit and that it is measured in ohms.

V=IR

OHM'S LAW

E=IR

We have said that the current that flows in a circuit depends upon the force or voltage applied to the circuit and on the opposition or resistance in the circuit. This means that the current depends both on the voltage and on the resistance.

If in an electrical circuit a voltage of 1 volt is applied to a circuit having a resistance of 1 ohm, a current of 1 ampere will flow in the circuit. If we double the voltage so that the voltage is 2 volts and the resistance is still 1 ohm, the current that will flow in the circuit will be 2 amps. On the other hand, if the voltage is 1 volt, and we double the resistance to 2 ohms, the current that will flow in the circuit will be only 1/2 amp.

This relationship between current, voltage and resistance is known as "Ohm's Law". We will use Ohm's Law many times in future lessons. For the present, all you need to remember is that the current depends upon the voltage and the resistance. If you double the voltage and keep the resistance constant, the current will double. If you cut the voltage in half and keep the resistance constant the current will be cut in half. On the other hand, if you keep the voltage constant but double the resistance the current will be cut in half but if you keep the voltage constant and cut the resistance in half the current will double. Increasing the voltage increases the current, reducing the voltage reduces the current. Increasing the resistance reduces the current and reducing the resistance increases the current.

SUMMARY

Here are the important points you should remember from this section of the lesson:

1. If a flashlight cell is connected to a wire made up of a material from which some of the electrons can be displaced, electrons will move from the negative terminal of the cell through the wire to the positive terminal, and through the cell back to the negative terminal making a complete circuit. The

cell provides the force that sets the electrons in motion.

2. A movement of electrons through the circuit is called a "current". In a simple circuit such as shown in Figs. 10 and 11, the movement of electrons is the same at all points in the circuit. Also, remember that once the wire is connected to the two-battery terminals and the electron movement starts, it starts the same instant in all parts of the circuit.
3. The unit used to measure the strength of an electric current is the ampere.
4. The unit of force that sets the electrons in motion is the volt.
5. The unit of resistance is the ohm.
6. The relationship between current, voltage and resistance is known as Ohm's Law.

SELF-TEST QUESTIONS

(h) Which terminal of a flashlight cell has a surplus of electrons? Which terminal has a shortage of electrons?

(i) When an electric circuit is completed do the electrons start in motion at the negative terminal of the battery first? At the positive terminal of the battery? Or do they start in motion instantaneously throughout the entire circuit?

(j) What is the unit in which we measure electric currents?

(k) What is the unit used to measure the electromotive force applied in an electric circuit?

(l) What unit is used to measure the opposition to current flow in an electric circuit?

(m) According to Ohm's Law, what effect on the electric current flowing in the circuit will increasing the voltage have?

INCREASED

(n) If we reduce the resistance in an electric circuit, will the current in the circuit increase or will it decrease?

Magnetism

Magnetism is as important in electronics as electricity. Without magnetism there would be no electronics industry at all, for magnetism and electricity work together to make our modern electronic devices possible.

PERMANENT MAGNETS

A magnet will pick up or attract small pieces of steel or iron. Minerals that have this property are found buried in the ground in some parts of the world. These minerals are called natural magnets. A piece of iron or steel can be made into a magnet by stroking it in one direction with a magnet. When we make a magnet in this way, we say that the metal is "magnetized". These magnets are called "permanent" magnets, because they will retain their magnetism almost indefinitely.

Originally, permanent magnets were made of iron or steel, but modern permanent magnets are usually made of an alloy called "Alnico". Alnico is a mixture of aluminum, nickel and cobalt. Very strong lightweight magnets, which retain their magnetism much better than magnets made of iron or steel, can be made from Alnico.

When a magnetized steel needle is suspended at its balance point by a light thread, as shown in Fig. 13, the needle will always line up in a direction corresponding closely to north and south. This phenomenon led to the first practical use for magnets, in compasses used by early sea voyagers and travellers. Compasses are made simply of a magnetized piece of steel that is mounted on a delicately pivotted bearing that will turn as easily as the needle suspended by the thread.

POLES OF A MAGNET

The ends of a permanent magnet are called "poles". This name was given to the ends of a magnet because the ends point toward the poles of the earth when the magnet is free to pivot on an axis. The pole that points toward the north pole of the earth was originally called the "north-seeking" pole. However, for simplicity the name has been shortened to the "north pole". The magnetic pole that points to the south pole of the earth is called the "south pole".

If two magnets are brought near each other, the north pole of one

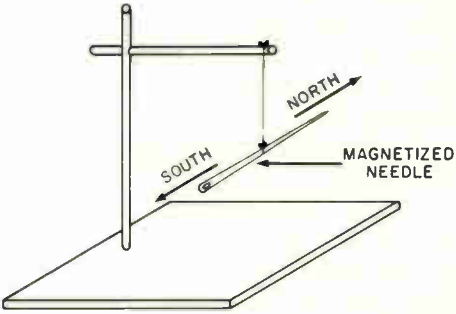


Fig. 13. If a magnetized needle is suspended at its balance point by a thin thread, the needle will line up in a north and south direction like a compass, because it lines up with the magnetic field of the earth.

magnet will repel the north pole of the other. Similarly, the south pole of one magnet will repel the south pole of another magnet. However, the north pole of one magnet will attract the south pole of the other magnet. The reason why a compass always points in a north-south direction is that the earth itself is a magnet, and one pole of this large magnet is near the north geographic pole, and the other pole is near the south geographic pole. The north pole of the earth attracts one of the poles of the magnet and repels the other. The south pole of the earth attracts the pole that is repelled by the north pole, and repels the pole that is attracted by the north pole. Therefore, the magnet will point in a direction so that one pole points toward the north magnetic pole and the other pole points toward the south magnetic pole.

Notice the similarity between the attraction and repulsion of magnetic poles and the attraction and repulsion of electric charges. You already know that "like charges repel and unlike charges attract". In magnets, "like poles repel and unlike poles attract". This is a fundamental law of magnetism; you should remember it.

MAGNETIC LINES OF FORCE

There are lines of force surrounding a magnet. You can trace out the lines of force around a magnet by using a small compass. If you bring the compass near the north pole of the magnet, the south pole of the compass will be attracted to the north pole of the magnet. The compass needle will line up with the magnetic lines of force. If you move the compass as shown in Fig. 14, you will be able to trace out the lines of force. The lines of force are shown coming from the north pole of the magnet and going to the south pole. We do not know for sure whether or not this is true, but there is considerable evidence that the lines of force actually do go from the north pole to the south pole and therefore we will base our explanations on this assumption.

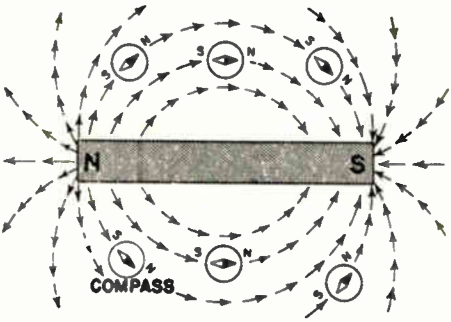


Fig. 14. A small compass can be used to trace magnetic lines of force near a permanent magnet.

Another experiment that can be performed to show the lines of force around a magnet is to place a thin sheet of cardboard over a magnet and then sprinkle iron filings evenly over the sheet of cardboard. Tap the cardboard gently, and the iron filings will arrange themselves in definite lines, producing the pattern shown at the top in Fig. 15.

If two magnets are arranged so that their north poles are placed close together and then iron filings are sprinkled on a cardboard placed over the magnet, the iron filings will arrange themselves as shown in the center of Fig. 15. Notice that you can see the lines of force from the north poles of the two magnets actually repelling each other.

You would get a third pattern by

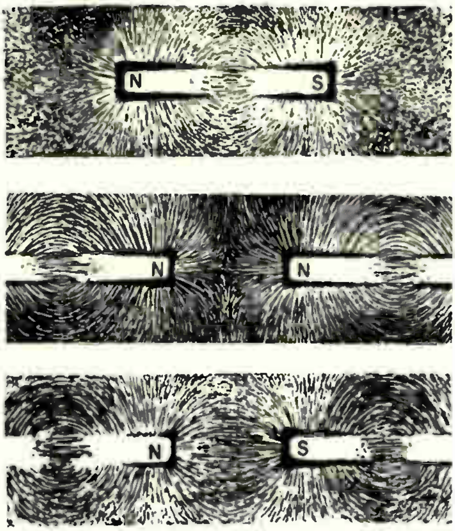


Fig. 15. If iron filings are placed on a sheet of cardboard over permanent magnets, they will trace out lines of force as shown here.

placing the north pole of one magnet toward the south pole of another and sprinkling iron filings on a cardboard. The pattern you would get in this case would be like the one shown at the bottom in Fig. 15. Here you can see the attraction between the north pole and the south pole of the two magnets.

The lines of force coming from a magnet are called "magnetic lines of force". They are similar to the lines of force surrounding electrically charged objects. The lines of force around an electrically charged object are called "electric lines of force".

ELECTRO MAGNETS

An electric current flowing through a wire produces a magnetic field in the space around the wire. This is called "electro magnetism". The circular lines of force around the wire can actually be traced out with a compass. There will be many of these magnetic rings surrounding the entire length of the wire. The magnetic lines of force close to the wire will be much stronger and more easily detected than those at some distance from the wire as shown in Fig. 16. However, even with a weak current flowing through a wire, magnetic lines of force can be detected some distance from the wire, with sensitive equipment.

Even though the magnetic lines of force around a current-carrying wire can be detected, the magnetic field will be weak unless the current flowing through the wire is very strong. However, by winding the wire in the form of a coil, a strong magnet can be made. When the wire is bent into a loop, the circular magnetic rings pass through the center of the coil in the same direction and reinforce each other as shown in Fig. 17.

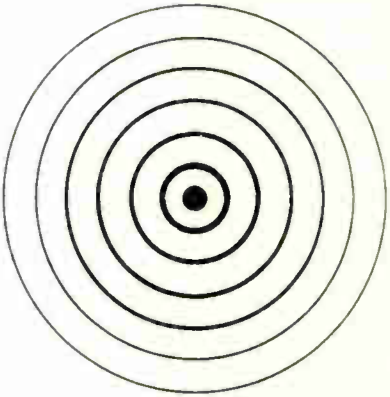


Fig. 16. When electrons flow through a wire, magnetic lines of force surround the wire. This is a cross-sectional view.

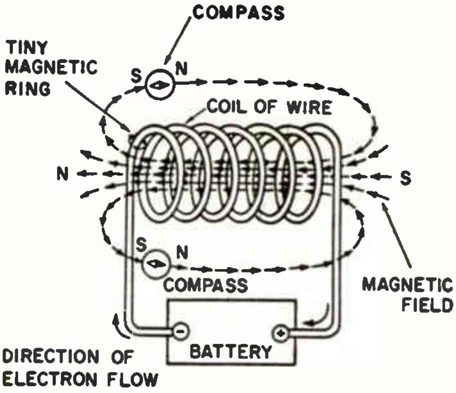


Fig. 17. The more turns of wire we have in a coil, the stronger the magnetic field will be when electrons flow through the coil.

This type of magnet is called an "electromagnet". The magnetic effect exists only as long as the current is flowing through the wire. Once the current is stopped by opening the circuit, the magnetic effect will disappear. Many parts used in electronic equipment depend upon the basic principles of electromagnetism to operate.

The electromagnet shown in Fig. 17 can be made much stronger by inserting an iron bar or a bar of some magnetic material inside the coil. The iron bar is called a "core". The actual increase in the strength of the magnet will depend upon the type of core material used.

You probably wonder why inserting a core inside the coil makes the magnet stronger. The answer to this question is that the iron core is made up of millions of tiny particles of iron. Each of these particles is itself a magnet having a north pole and a south pole. Ordinarily, these tiny magnets are not arranged in any definite pattern. One might point in one direction and another in a second direction, and a third in still another direction as shown in Fig. 18A. As a result of the random arrangement of these small magnets, the magnetic field of one magnet is cancelled by the magnetic field of another. However, when the iron core is placed in the magnetic field inside the current-carrying coil, the magnetic field produced by the coil causes the particles to line up and all point in the same direction as shown in Fig. 18B. When this happens, the entire bar becomes one strong magnet. However, most of the tiny particles are kept lined up only by the magnetic field produced by the current flowing in the coil. Once this field is removed by opening the circuit so that the current can no longer flow through the coil, most of the tiny particles will return to their random arrangement so that they will no longer be pointing in one direction, and most of the magnetic field will disappear.

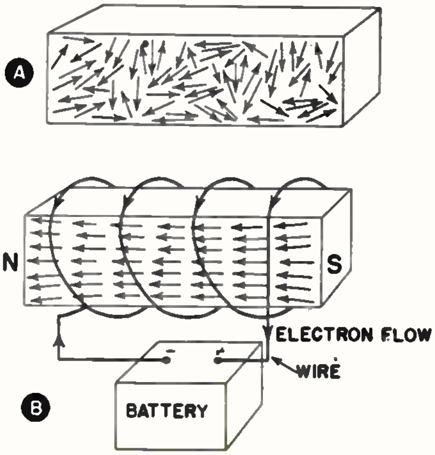


Fig. 18. In an unmagnetized bar of iron at A, the tiny magnets in the iron do not line up; if the bar of iron is magnetized, they will line up as at B.

INDUCED CURRENTS

We have seen that there is a magnetic field around a current-carrying wire, and that if a current flows through a coil, an electromagnet will be produced. Now, is the opposite true? If a coil is placed inside a magnetic field will a current flow through the coil? Let us look in the experiment illustrated in Fig. 19. Here we have a coil wound on a hollow form. The ends of the coil are connected to a small flashlight bulb. We have used a combination of a pictorial drawing for the coil and a schematic symbol for the bulb.

If a magnet is moved quickly inside the hollow form, the bulb will light while the magnet is being moved into the coil. Once the magnet is completely inside the coil and no longer moving, the bulb will no longer light. When the magnet is moved quickly out of the coil, the bulb will light again. If the magnet is moved quickly in and out of the coil, the bulb will light and remain lighted as long as the magnet is in motion. As long as the magnet is moving inside the coil, a current will flow in the coil and through the flashlight bulb.

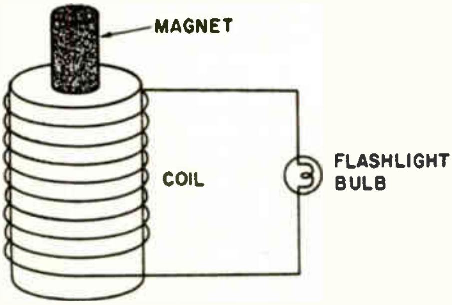


Fig. 19. If a magnet is moved in and out of a coil connected to a flashlight bulb, the magnetic lines of force cutting the turns of wire on the coil will induce a voltage in the coil, and the voltage will cause a current flow through the flashlight bulb.

This current flows because a voltage is induced in the coil. The magnetic lines of force moving through the turns of wire on the coil are said to cut the turns of wire on the coil. A small voltage is induced in each turn on the coil as long as the number of magnetic lines of force cutting the turn is changing. The voltages induced in the various turns of wire on the coil add together. This total voltage produces a current flow through the coil and through the flashlight bulb. We call the voltage produced an "induced" voltage and the current an "induced" current.

A second demonstration of an induced voltage is shown in Fig. 20. Two coils are wound on the same form and placed near each other. It is customary on schematic diagrams to use letters to designate the various parts. L is usually used for coils. We have marked the coils L1 and L2 to make them easy to refer to. One coil, which we have marked L1, is connected to a flashlight cell through a switch, and the other coil marked L2 is connected to a flashlight bulb. Inserted through the form on which the coils are wound is an iron core to increase the strength of the magnetic field. We have shown the schematic symbol for the switch, and labelled it SW. This makes three schematic symbols you should know now, the flashlight cell, the light bulb and the switch.

When the switch is closed and current starts to flow in L1, there will be a voltage induced in L2 and a glow will be seen in the flashlight bulb. However, this glow will last for only

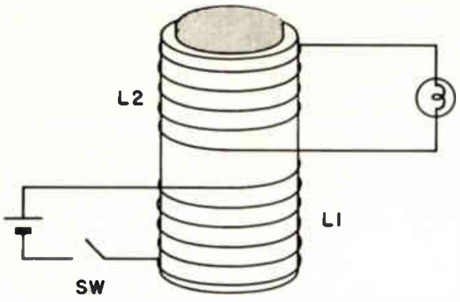


Fig. 20. When the circuit to L1 is opened or closed, a voltage will be induced in L2.

an instant after the switch is closed. When the switch is open and the current flow in L1 is interrupted, the bulb again will glow, indicating that this too induced a voltage in the second winding.

The explanation of this action is the same as for the voltage induced by the magnet moving in and out of the coil in Fig. 19. When the circuit is completed by closing the switch, current starts to flow in the coil. But the magnetic field that accompanies the current flow does not build up instantly; it takes just a short time for this field to build up. When the field is building up, the magnetic lines cutting the turns of L2 are changing just as they cut the coil when the magnet was moved into the coil in Fig. 19. While the magnetic field in L1 is building up, the number of magnetic lines of force is increasing. This change in the number of magnetic lines of force cutting L2 induces a voltage in L2 which causes a current to flow through it and the flashlight bulb. When the circuit is open, the magnetic field must disappear. The number of magnetic lines of force again must change and while this is happening, the change in the number of magnetic lines of force cutting L2 again induces a voltage in L2 which causes the current to flow.

It is important for you to realize that whenever a magnetic field around a coil changes, there will be a voltage induced in the coil. Remember this, it is important; you will be dealing with induced voltages as long as you are in the field of electronics.

SUMMARY

There is a great deal of similarity between magnetism and electricity. Indeed, the basic law of magnetic forces - "like forces repel, and unlike forces attract", is the same as the basic law of electricity, "like charges repel and unlike charges attract". As you go on through your course you will see that electricity and magnetism work together to make the electronic devices that we use today possible.

You are not expected to remember all the details described in this section on magnetism. The information is presented so you will have a complete picture and be able to understand magnetism completely. The important points that you must remember from this section are as follows:

1. A magnet has a north pole and a south pole.
2. Magnetic lines of force travel from the north pole of the magnet around through space to the south pole of the magnet.
3. Like magnetic poles repel; unlike magnetic poles attract.
4. There is a magnetic field around a current-carrying wire.
5. An electromagnet can be made by passing a current through a coil.

6. Inserting an iron core into an electromagnet will result in a stronger magnetic field.
7. If the magnetic lines of force cutting a turn of a coil change, there will be a voltage induced in that turn of the coil.
8. If the magnetic lines of force cutting all the turns of a coil change there will be a voltage induced in each turn of the coil and these voltages will add together. If the coil is connected into a complete circuit, current will flow in the circuit.

SELF-TEST QUESTIONS

(o) State the basic law of magnetism.

(p) If a pole of a magnet attracts the south pole of a compass, is the pole a north or south pole?

(q) In which direction do the magnetic lines of force coming from the poles of a magnet travel?

(r) Where are the magnetic lines of force around a current-carrying wire strongest - close to the wire or at some distance from the wire?

(s) What effect will placing an iron core inside of an electromagnet have on the strength of the magnetic field?

(t) If the ends of a coil are connected to a flashlight bulb, and a very strong permanent magnet is placed inside of the coil, will the flashlight bulb light? How long will the flashlight bulb remain lit?

(u) In the circuit shown in Fig. 20, when the switch is first closed, the flashlight bulb will glow. Why doesn't the flashlight bulb continue to glow as long as the switch is closed?

Electronic Components

The parts used in electronics equipment are often simply called parts, but they are sometimes called components. The two words mean the same thing; we'll use both words so you will get familiar with them.

In the rest of this lesson, you will study a few of the parts found in electronic equipment. We are simply going to introduce these parts; you will study them in detail in later lessons.

You have already seen the schematic symbol for a single-cell battery such as the flashlight cell, for a light bulb and for a switch. You will learn the symbols used for several other parts. It is important that you learn these symbols as you go along. The symbols are used to draw schematic diagrams. Schematic diagrams tell you how the various parts are connected together. You must learn how to read this type of diagram. Manufacturers supply schematic diagrams of electronic equipment, they do not supply picture diagrams. As a matter of fact, picture or pictorial diagrams would be far more complicated and far more difficult to read than schematic diagrams. Once you learn how to read schematic diagrams you will find that they tell you far more about how a circuit is connected than a pictorial diagram could possibly do.

It is quite a job to learn all the schematic symbols at once, but if you take them one at a time, as you come to them in your lessons, and also learn how to read the simple schematic diagrams that will be shown in the early lessons, you will soon find that you know the symbols and that schematic diagrams are really quite easy to follow. If you learn how to read the simple schematic diagrams in the beginning, when you get along further in your course you will find that the large complex diagrams, that you will have to deal with later, are very easy to follow.

CONDUCTORS AND INSULATORS

When we connect parts together in an electronic circuit there will be certain paths through which we want electrons to flow, and other places where we want to avoid a current flow. We use conductors to provide the paths for current flow and insulators where we want to prevent current flow.

There are a number of materials from which one or two electrons in the outer ring of electrons can be displaced. Copper, silver, aluminum, iron and most metals are examples of this type of material. Since electrons can be displaced from these materials it is easy to set them in motion in a wire made of this type of material, and cause a current to flow through the wire. These materials are called conductors. They are so called because they will conduct or transmit an electric current; in other words a current flow can be set up in them. The lines used to connect parts together on schematic diagrams represent the wire conductors used to provide paths for current flow.

There is no such thing as a perfect conductor. All conductors offer some resistance, or opposition, to an electric current. Silver is the best known conductor, but it is used only in special applications because it is too expensive. Copper, which is almost as good a conductor as silver, is used in most wire because it is less expensive than silver. Copper wire is used almost exclusively in connecting electronic components together. It is also used in coils. However, in some special applications where it is essential to keep the resistance as low as possible you will find that silver wire or silver plated copper wire is used. You will learn about these special applications later.

There are other materials which will not readily give up any electrons. A material having its outer ring full of electrons has no place to permit any additional electrons to move into the atom nor will it willingly permit any electrons to move from any of its rings. This type of material is called an insulator. It normally will not pass or conduct an electric current.

There is no such thing as a perfect insulator. Even in materials having all the electron rings filled, an electron will occasionally escape, particularly if enough force is applied to the material. However, the number of electrons that will escape is usually so small, that for all practical purposes we can say that these materials will not conduct current. When an extremely high force is applied to this material, electrons may be forced out and the material will break down, and no longer will be usable as an insulator.

Most copper wire that you will use in electronic equipment to connect the various parts together will be covered with a rubber coating or a plastic coating. The coating is an insulator. Its purpose is to keep the current flowing through the wire to the part it is supposed to reach and prevent its travelling through another circuit. If we did not use an insulator over the wire, and two wires happened to accidentally touch, we might have a short circuit where current would simply flow out one wire and back to the battery and perform no useful service. With an insulating material around the wires, the insulator will prevent this from happening.

BATTERIES

You already know that a flashlight cell is a device that can force electrons through a circuit. You know that the cell has two terminals, a positive terminal and a negative terminal. You know that when the flashlight cell is connected into a circuit, electrons will leave the negative terminal of the cell, flow through the circuit and back to the positive terminal of the cell. You also know that the voltage of a flashlight cell is about 1.5 volts.

Sometimes we need more voltage than can be obtained from a single flashlight cell. For example, you have surely seen a flashlight in which two cells are used. In such a flashlight the cells are arranged as shown in Fig. 21A. The positive terminal of one cell connects to the center terminal on a flashlight bulb. The positive terminal of the second cell is connected to the negative terminal of the first cell. The negative terminal of the second cell connects to a switch and through the switch to the threaded part of the bulb. When the switch is closed current flows

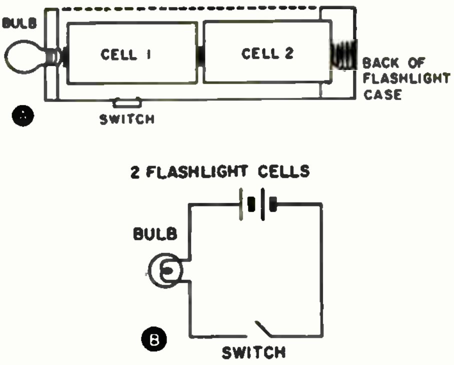


Fig. 21. Two flashlight cells used in series to power a 3-volt flashlight bulb are shown at A. The schematic diagram of this circuit is shown at B.

from the negative terminal of cell 2 through the switch and then through the bulb to the positive terminal of cell 1, through cell 1 to the negative terminal of cell 1 and across to the positive terminal of cell 2 and then through cell 2. Schematically the circuit is shown in Fig. 21B.

In a circuit of this type we say that the two cells are connected in series. Each cell provides a voltage of 1.5 volts so that the total voltage applied to the flashlight bulb is 1.5 + 1.5 or 3 volts.

You can obtain devices in which two cells similar to a flashlight cell are put in a single container to provide a total output voltage of 3 volts. When two cells are put together like this we call it a battery. In other words, a battery is simply a device in which there are several cells. Often we call a flashlight cell a flashlight battery; technically this is not quite correct, but it has come into such wide usage that everybody knows what is meant and as a result the expression is used.

In some applications in electronics you might need a voltage of 4.5 volts. To get this voltage all you need to do is connect three 1.5 volt flashlight cells in series and the voltages will add to give you a voltage of 4.5 volts.

Many of the small portable transistor radios in use today use a small 9-volt battery. Batteries of this type are simply made up of six small cells similar to the flashlight cell. Six times 1.5 gives you a voltage of 9 volts.

In the early days of radio 22.5 volts and 45-volt batteries were widely used. A 22.5 volt battery had fifteen 1.5 volt cells connected in series to give a voltage of 22.5 volts and a 45-volt battery simply had thirty 1.5-volt cells connected in series to give a voltage of 45 volts.

A 3-volt battery is generally indicated schematically by the symbol for two cells arranged such as shown in Figs. 21B and 22A. A 4.5-volt battery usually used three cell symbols as shown in Fig. 22B. However, if we wanted to show a 22.5 or 45-volt battery it would be too tedious to draw the symbol for the required number of cells so the symbol usually shows 5 or 6 cells connected in series such as shown in Fig. 22C and then the voltage is written either above or below the cell as indicated in the figure.

When cells are connected so that

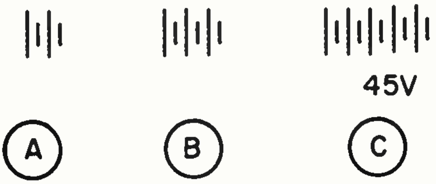


Fig. 22. Schematic symbol for two cells in series is shown at A. Symbol for three cells in series is shown at B. C is symbol for 45V battery.

the negative terminal of one is connected to the positive terminal of another to produce a battery, the total battery voltage is equal to the voltage of the individual cells times the number of cells. However, sometimes a number of cells are connected so that the positive terminals of all the cells are connected together and the negative terminals of the cells are connected together. When cells are connected in this way, we also refer to the device as the battery. However, a battery of this type has an output voltage equal to the voltage of only one cell. We say that the cells are connected in parallel.

You might wonder why we would want to connect cells in parallel. The answer is that in some applications we may need more current than can be supplied by a single cell. In this case by connecting a number of cells in parallel, each cell can supply part of the required current and the total number of cells is connected together to form a battery that is capable of supplying the current required.

This might immediately bring up a question - why not simply make a bigger cell that is capable of supplying the current needed. This can be done, but often manufacturers are making certain size cells in very large quantities and therefore they can make them at a low cost. To make a single cell that could supply two or three times the current capacity of a single cell might cost as much as ten or fifteen times what it would cost to make the smaller cell that they were making in very large quantities. Therefore it is more economical to take three or four of these smaller cells and connect them in parallel for applications where high currents are required than it would be simply to make one special cell that could supply the currents and have to make them only in limited quantities.

When a number of cells are connected in parallel and the output voltage is only 1.5 volts we usually use the same schematic symbol as we use for a flashlight battery. This symbol indicates the voltage, it does not indicate that the cell is capable of a higher current than a flashlight cell. If we want to make it clear that we have several cells connected in parallel, we can use the symbol shown in Fig. 23. This symbol shows four cells connected in parallel.

Other Types of Batteries.

The flashlight cell is only one type of cell. There are many other types of cells. For example, there is the lead cell which is used in storage batteries found in automobiles. Six lead cells are arranged in series in the average automobile battery found in late model cars. In older cars three cells were connected in series. The lead cell has a voltage of about 2 volts so that modern cars have a 12-volt battery in it whereas older cars have 6-volt batteries.

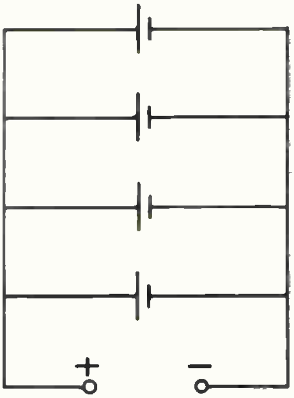


Fig. 23. Four cells connected in parallel.

Other types of cells used today are the mercury cell and the manganese cell. You will study these cells and batteries made up of these cells in later lessons.

COILS AND TRANSFORMERS

You have already been briefly introduced to coils and you know that if the number of magnetic lines of force cutting a coil changes, a voltage will be induced in the coil. In electronics you will run into all kinds of coils. In the tuners of television receivers designed to receive the ultra high frequency channels, you will find coils that have only one or two turns. In other applications you will find coils having many turns. The schematic symbol used to represent a coil is shown in Fig. 24A. This should not be too hard to remember because the symbol itself looks something like a coil.

Fig. 24. Schematic symbols for coils. The lines above the coil at B indicate an iron core.

We mentioned previously that sometimes an iron core is placed inside the coil, and that placing the iron core inside of the coil will greatly increase the magnetic field produced by the coil. Often in electronics there will be iron cores used inside of a coil. When a coil has an iron core, a schematic symbol like that shown in Fig. 24B is usually used. The lines placed beside the coil symbol indicate that the coil has an iron core.

Probably no device has done more for the electronics industry than the transformer. The transformer has made it possible for power companies to supply homes and industry with electric power economically. Without economical power there could be no electronics industry. There is hardly a piece of electronic equipment made that does not use one or more transformers.

In spite of the importance of the transformer, it is basically a simple device. A transformer in its simplest form is nothing more than two coils mounted close together. The two coils we discussed in Fig. 20 actually can be called a transformer. Two typical transformers and the schematic symbols for them are shown in Fig. 25. The transformer shown in Fig. 25A consists of two coils wound on a cardboard frame. This type of coil is called an air-core transformer. The one shown in Fig. 25B is made of two coils wound on iron core. This type is called an iron-core transformer.

Air-core transformers such as shown in Fig. 25A are used in radio frequency applications. By radio frequency we mean radio signals. Iron-core transformers such as shown in Fig. 25B are used in power

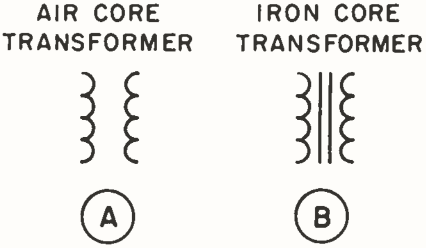


Fig. 25. Schematic symbols for transformers. The transformer at A is an air-core transformer, the one at B, an iron-core transformer.

applications. You will find out what the difference is between radio frequency signals and power frequencies in your next lesson.

We do not expect you to know all there is to know about coils and transformers at this time, the only thing we want you to remember is the schematic symbols used for coils and the schematic symbols used for transformers. You will go into great detail on these important parts in a later lesson.

CAPACITORS

An important electronic part is the capacitor. Basically a capacitor is simply two metal plates that are placed close together. The plates do not touch, they may be separated simply by an air space or some other material may be placed between the two plates of the capacitor.

If a battery is connected to the two plates of the capacitor, the negative charge on the negative terminal of the battery will try to force additional electrons into the one plate of the capacitor. These electrons will repel electrons from the other plate of the capacitor and they in turn will flow towards the positive plate of the battery. As a result, we will build up a charge on the two plates of the capacitor as shown in Fig. 26A. Notice that one plate of the capacitor has a negative charge and the other plate has a positive charge. The schematic symbols used for a capacitor are shown in Fig. 26B. You will find both types of symbols used. As you might expect the two lines represent the two plates of the capacitor. Be sure that you remember the schematic symbols. Capacitors are among the most important parts used in electronics. There are many different sizes and different types; capacitors are so important that we will devote an entire lesson to them and to their uses later.

RESISTORS

Earlier in this lesson we mentioned that conductors were used to carry the electric current from one

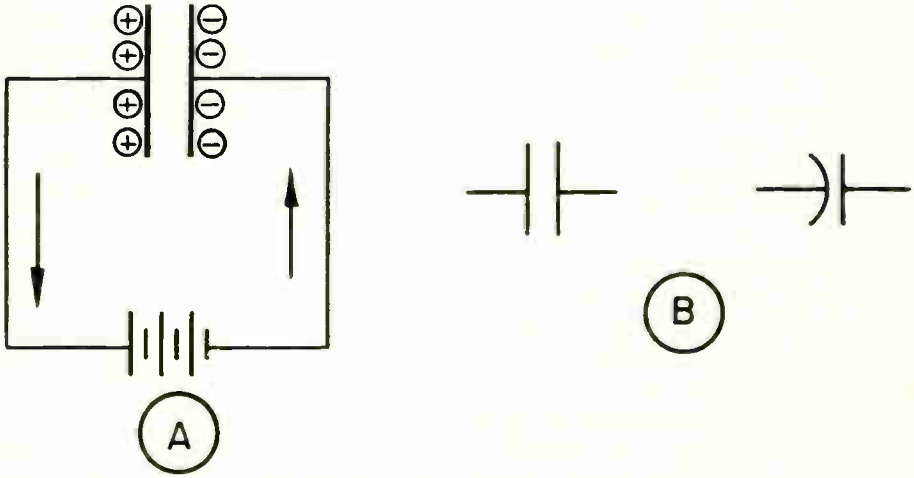


Fig. 26. The circuit at A shows how a capacitor can be charged. The schematic symbols are shown at B.

part of a circuit to another. We pointed out that the materials used in conductors were selected because they had electrons readily available and offered little or no opposition to the flow of electric current through them. In some applications we want to offer opposition to the flow of electric current. In these cases we use a device called a resistor. A resistor may be made of a carbon-type composition or it can be made of a wire that does not have as good conduction capabilities as copper has. In electronics you will run into resistors having a resistance of only a few ohms up to resistors that may have a resistance of well over 1,000,000 ohms.

Fig. 27. The schematic symbol for a resistor.

The schematic symbol for a resistor is shown in Fig. 27. The actual resistance of the resistor is usually written beside the schematic symbol as in Fig. 27. Here we have a resistor that has a resistance of 220 ohms and we have indicated this value above the resistor.

In any piece of electronic equipment you will probably find more resistors, capacitors and coils than any other parts. As a result, their schematic symbols will appear most frequently on schematic diagrams.

Be sure you remember the symbols used for each of these three important parts. Resistors are so important and so widely used that you will go into detailed study of them in a later lesson and you will be dealing with them throughout your entire electronics career.

VACUUM TUBES

Vacuum tubes are so widely used today that almost everyone has seen one. Since tubes are so widely used, it is important for you to learn something about their operation as soon as possible.

The Diode Tube.

The simplest vacuum tube is the diode tube. In the diode tube a filament that can be heated to a red heat by passing a current through it is placed inside of a glass envelope. Around the filament is a metal cylinder called the plate. Leads are brought out of the glass envelope for the two filament leads and for the plate lead. All the air is evacuated from the inside of the glass envelope before the envelope is sealed. The schematic symbol for a diode tube is shown in Fig. 28.

We mentioned earlier that in an atom, the electrons were rotating about the nucleus of the atom. In a diode tube the electrons are rotating about the nucleus of the atom in the material used for the filament. When a battery is connected between the filament terminals as shown in Fig. 29A, the filament is heated to a red heat. This causes the motion of the electrons to speed up and many of

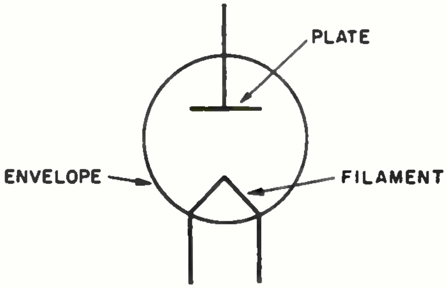


Fig. 28. The schematic symbol of a two-element (diode) tube.

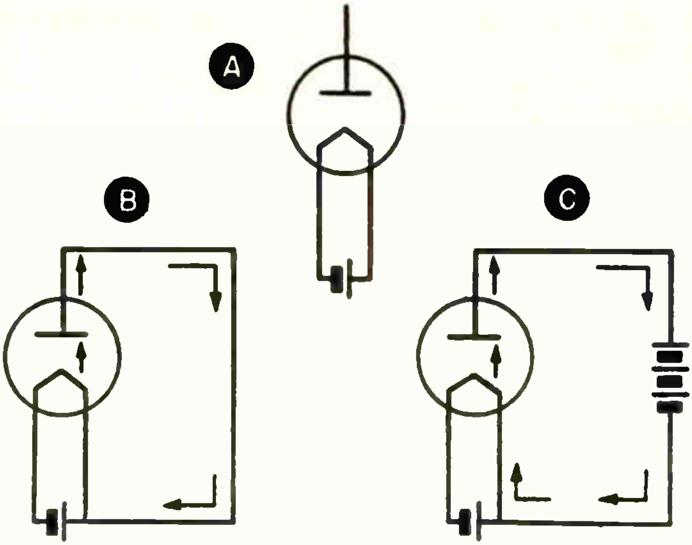


Fig. 29. The filament of a diode is heated as shown at A. When a diode is connected as shown at B, a small current will flow in the direction indicated by the arrows. When a battery is added as in C, a much stronger current will flow.

the electrons to break loose from the atom and fly off into space around the filament of the tube. If we connect the lead from the plate of the tube back to the filament as shown in Fig. 29B, some of the electrons that fly off the filament will travel through the space from the filament of the tube over to the plate and then flow from the plate through the external circuit back to the filament of the tube.

Since electrons have a negative charge they are attracted by a positive charge. Therefore if we connect a battery between the plate and the filament as shown in Fig. 29C, the electrons that fly off the filament of the tube will be attracted by the positive potential on the plate of the tube. As a result, many more of the electrons will travel from the filament over to the plate of the tube to the positive terminal of the battery. Electrons will travel through the battery to the negative terminal and from the negative terminal back to the filament of the tube.

Of course, as with any complete circuit, the current flow around the circuit is instantaneous. The instant the battery is connected to the tube current starts flowing around the circuit, and the amount of current flowing through the circuit is the same at all points in the circuit at all times.

Even though the diode tube is the simplest and the first tube invented, it is still in use today. The high-voltage rectifier used in television receivers today is nothing other than an improved version of this simple diode tube. Be sure that you remember the schematic symbol for the diode tube that is shown in Fig. 28 - this is an important symbol and you must remember it.

The Triode Tube.

While the diode tube is important,

and its discovery was a great milestone in the early days of electronics, it was not until the three-element tube called the triode tube was invented that the electronics industry as we know it today really got started. The schematic symbol of a triode tube is shown in Fig. 30. Notice that the symbol is the same as the symbol for the diode tube except that a third element has been added between the filament and the plate. This third element is called a grid.

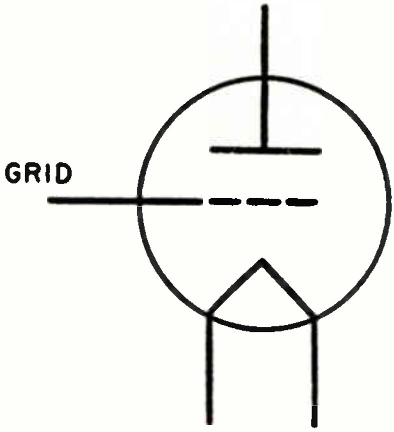


Fig. 30. The schematic symbol for a triode.

In a triode tube the filament is placed in the center of the tube. Around the filament, and close to it is a wire mesh; this is the grid of the tube. Placed some distance from the grid and around it is a round cylinder and this is the plate.

Because the grid is placed so close to the filament, a small voltage applied to the grid will have a large effect on the number of electrons that can flow from the filament to the plate of the tube. If the tube is connected into a circuit as shown in Fig. 31, you can see what will happen.

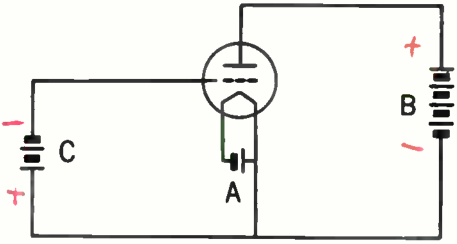


Fig. 31. A triode tube showing how three batteries are used to provide the necessary operating voltages.

The battery marked A is used to heat the filament of the tube. In early days of radio this battery was called the A battery. A small battery having a voltage of 3 or more volts is connected between the filament of the tube and the grid. This battery is labelled C on the diagram, and is called a C battery. Notice that the positive terminal of this battery is connected to the filament, and the negative terminal is connected to the grid. A battery having a somewhat higher voltage is connected between the plate of the tube and the filament. The positive terminal of this battery is connected to the plate and the negative terminal is connected to the filament. This battery is called a B battery.

Now let us see what happens in the tube. The filament of the tube is heated by the current from the A battery. This causes the filament to give off electrons and the electrons fly off into the space between the filament and the grid. However, many of the electrons are repelled by the negative charge on the grid of the tube due to the voltage of the C battery, and travel back to the filament. Some of the electrons manage to get through the grid and they are attracted by the positive potential applied to the plate of the tube by the B battery, and will travel over to the plate. The amount of current flowing from the filament to the plate of the tube can be controlled by the grid voltage. If we increase the negative voltage applied to the grid, the amount of current flowing through the tube will decrease, and if we reduce the negative voltage applied to the grid of the tube, the amount of current flowing from the filament of the tube to the plate will increase.

It is this ability of the grid to control the flow of current from the filament of the tube to the plate that makes the vacuum tube so useful in electronics. You will study vacuum tubes in detail in later lessons. For the present, you should remember how electrons flow from the filament of the tube to the plate of the tube and how the grid can control the flow of electrons through the tube. You should also remember the schematic symbols used to represent a diode (a two-element tube) and a triode (a three-element tube).

The schematic symbol of a triode tube with a cathode instead of a filament is shown in Fig. 32. In the triode tubes we have shown previously, the filament was heated by a battery and the filament gave off the electrons that were used in the tube. More modern tubes have a cathode that is designed to give off the electrons. The cathode is a hollow round tube and it is coated with a special material that readily gives off electrons when it is heated. Inside of the cathode is a heater. The heater is heated by an external voltage applied to it and the heat from the heater radiates to the cathode and heats the cathode to a temperature where it will give off electrons.

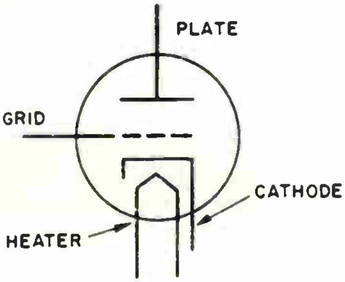


Fig. 32. Schematic symbol of a triode tube with a cathode and a heater.

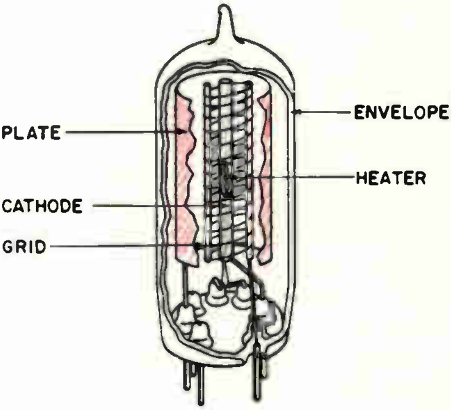


Fig. 33. Cut-away view of a typical vacuum tube showing its elements.

The cathode-type tube has replaced the filament-type tube in modern electronic equipment. The tubes used in modern radio and television receivers are all cathode-type tubes. A cut-away view of a modern tube is shown in Fig. 33. Filament-type tubes were used in portable receivers, but these have been replaced today by transistors.

TRANSISTORS

Transistors are made out of materials called semiconductors. Remember that a conductor is a material that will conduct or pass the flow of electric current. An insulator is a material that will not normally pass an electric current. A semiconductor is a material that falls midway between the two. It is neither a good conductor nor a good insulator.

Two materials, germanium and silicon are widely used in making transistors. Almost all the early transistors were germanium transistors, but now silicon transistors are about as numerous as germanium transistors. In the early days of semiconductors, manufacturing techniques had not been developed for the manufacture of silicon transistors. The few silicon transistors that were available were much more expensive than germanium transistors. However, today both types are widely available and there is very little difference between the price of the two.

A typical transistor is made up of three pieces of germanium or silicon as shown in Fig. 34. These three pieces are arranged as shown. Each piece of the germanium or silicon has been mixed with small quantities of another chemical. The pieces marked 1 and 3 have been mixed with the same chemical and the piece marked 2 has been mixed with small quantities of another chemical.

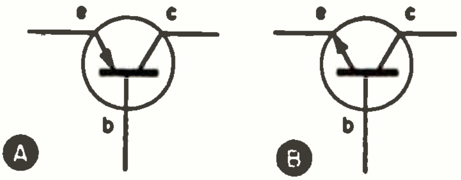


Fig. 35. Schematic symbols for two different types of three-element transistors. The emitter is marked e, the base b, and the collector c.

Since the transistor is made up of three pieces of material, it is often called a triode, just as the vacuum tube with the cathode, a grid and a plate is called a triode. The elements in a transistor are called the emitter, the base and the collector. The schematic symbols for transistors are shown in Fig. 35. The lead with the arrow on it and marked with the letter e, is the emitter, the long straight line marked b is the base and the other lead marked c is the collector. The two different types of symbols are for two different types of transistors. Their operation is somewhat different, but they can be used to accomplish the same thing.

The transistor is a comparatively new device compared to the vacuum tube. However, tremendous pro-

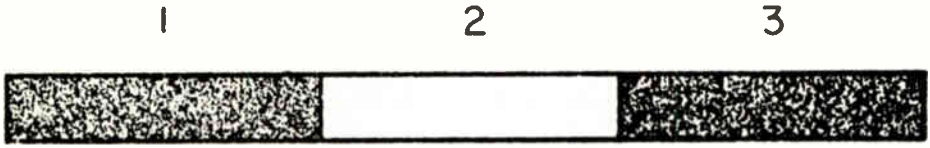


Fig. 34. A triode transistor made of three pieces of germanium. The germanium in the pieces marked 1 and 3 has been mixed with a small amount of one chemical; the germanium in the section marked 2 has been mixed with another.

gress has been made with the transistor in a relatively short space of time. Already, portable radio receivers using vacuum tubes have disappeared. All modern portable radio receivers use transistors. Also automobile radio receivers are now completely transistorized - they all use transistors. The only automobile radio you will find using vacuum tubes will be the automobile receiver designed for a car that is a number of years old.

Since transistors are making such important strides, it is extremely important that you learn all you can about them. For the present, simply remember the symbols used for them, and remember the names of the different elements in a transistor. Later, you will have several lessons devoted exclusively to transistors and you'll study transistor circuits in many of your more advanced lessons.

SUMMARY

In the preceding section you were introduced to many of the parts that you will study in detail in later lessons and will work with in your experimental kits. As we pointed out, it is important that you learn the schematic symbols for these parts as you go along, and also follow the simple circuits as you come to them. If you will do this as you go through your course you will find that schematic diagrams are easy to read, and you will soon be able to read fairly complicated diagrams without too much trouble.

There are a number of important points in this lesson that you should remember:

1. Conductors are used to carry currents from one part to another and insulators are used to keep the current from flowing where it is not wanted.
2. Batteries are made of groups of cells. If the cells in a battery are connected in series, that is the positive terminal of one connected to the negative terminal of the other, the voltages of the cells add so that the total battery voltage will be equal to the voltage of the cell times the number of cells in the battery.
3. When cells are connected so that the positive terminals of the cells are connected together and the negative terminals are connected together we say that the cells are connected in parallel.
4. Coils and transformers are widely used in electronics. A coil is simply made of a number of turns of wire. A transformer consists of two or more coils placed close together so that the magnetic lines of force produced when a current flows through one coil will cut the turns of the other coils. Remember the symbols used for air core coils and transformers and for iron core coils and transformers.
5. A capacitor is a device that can store an electric charge. It is made of two metal plates placed close together. Review the symbol used to represent a capacitor.
6. Resistors oppose the flow of current through them. Resistors having a resistance of only a few ohms up to resistances of over 1,000,000 ohms will be found in electronic equipment.
7. Two important types of vacuum tubes are the diode tube and the triode tube. A diode tube has two

elements, a triode tube has three elements.

8. Transistors are made of materials called semiconductors. Germanium and silicon are used in the manufacture of transistors. A transistor has three elements called an emitter, a base and a collector.

SELF-TEST QUESTIONS

(v) Name three materials that are good conductors.

(w) What metal is most widely used as an electrical conductor?

(x) If four 1-1/2 volt flashlight cells are connected in series to form a battery, what will the battery voltage be?

(y) Draw the schematic symbol of a 90 volt battery.

(z) Draw the schematic symbol for an air core coil.

(aa) Draw the schematic symbol for an iron core transformer.

(ab) What is the name of the device that can store an electric charge?

(ac) Draw the schematic symbol of a capacitor.

(ad) Name the three elements of a triode vacuum tube.

(ae) Name the three elements of a transistor.

Answers to Self-Test Questions

(a) Like charges repel, unlike charges attract.

(b) An atom is the smallest particle of an element that retains the original characteristics of the element. The atom will have a nucleus at its center and a number of electrons revolving around the nucleus.

(c) The nucleus and the electrons.

(d) The nucleus has a positive charge - the electrons have a negative charge.

(e) The copper atom will have a positive charge. If the atom loses one of its electrons, there will not be enough electrons to completely neutralize the positive charge on the nucleus and therefore the atom will have a positive charge.

(f) Electrons in adjacent atoms repel each other because all electrons have a negative charge and like charges repel.

(g) If you draw a diagram of the two atoms, you will soon see the answer to this question. The one atom that has the ten electrons will have two electrons in the first ring and eight electrons in the second ring. This is illustrated in Fig. 4 which shows the maximum number of electrons that can be in each ring. The atom that has eleven electrons will have two electrons in the first ring, eight electrons in the second ring, and the eleventh electron in the third ring. This atom will be quite unstable because the single electron in the third ring will not be held very closely to the nucleus. Indeed, this is the structure of the sodium atom. Sodium is a metal which in its pure state is so unstable that it must be kept submerged in oil. The atom with the ten electrons has the first two rings filled. You will remember that we said that atoms with the outer ring filled are very stable. This atom is indeed stable, it is the neon atom. Neon is called an inert gas by chemists. This means it is chemically inactive and will not combine with other elements.

(h) The negative terminal of a flashlight cell has a surplus of electrons. The positive terminal has a shortage. As a result, when a flashlight cell is connected into a circuit, the electrons leave the negative terminal, flow through the circuit and travel back to the positive terminal of the cell.

(i) When an electric circuit is completed, electrons start in motion instantaneously throughout the entire circuit. In a simple circuit such as shown in Figures 11 and 12, the number of electrons in motion is the same in all parts of the circuit.

(j) We measure electric currents in amperes. We usually abbreviate amperes, amps.

(k) The unit used to measure electromotive force is the volt.

(l) The unit used to measure the opposition to current flow in an electric circuit is the ohm.

(m) Increasing the voltage in an electric circuit will increase the current flowing.

(n) If we reduce the resistance in an electric circuit, the current flowing in the circuit will increase.

(o) The basic law of magnetism is, "like poles repel; unlike poles attract".

(p) The basic law of magnetism will give you the answer to this question. Since the pole of the magnet attracts the south pole of the compass, the pole must be an unlike pole, therefore it is a north pole.

(q) The magnetic lines of force leave the north pole of the magnet and travel through space to the south pole of the magnet.

(r) The magnetic lines of force around a current-carrying wire are strongest close to the wire. The further you get away from the wire, the weaker the magnetic lines of force will be.

(s) Placing an iron core inside of an electromagnet will increase the strength of the magnetic field.

(t) The flashlight bulb will light while the magnet is being placed inside of the coil. Once the magnet is inside of the coil and no longer moving, the flashlight bulb will no longer light.

(u) In the circuit shown in Fig. 20, when the switch is first closed, the magnetic field in L1 builds up slowly. This causes the number of magnetic lines of force to increase and the changing number of magnetic lines of force cutting L2 induces a voltage in L2. Once the magnetic field around L1 is built up to its full strength, the number of magnetic lines of force cutting L2 will no longer change and there will be no voltage induced in L2, therefore the flashlight bulb will no longer light.

(v) Copper, silver, aluminum, iron and most metals are good conductors.

(w) Copper.

(x) When the flashlight cells are connected in series the voltage will be equal to the cell voltage times the number of cells. 1-1/2 times 4 = 6 volts.

(y) See Fig. 22C, use the same symbol but write 90 v instead of 45 v.

(z) See Fig. 24A.

(aa) See Fig. 25B.

(ab) A capacitor.

(ac) See Fig. 26B.

(ad) Plate, grid and filament or cathode.

(ae) Emitter, base and collector.

Answering The Questions

On the last page of this lesson you will find ten questions. These questions are designed to help you learn the important points in this lesson. We do not want you to try to memorize the lesson or answer the questions from memory.

When you are ready to answer the questions, read over the first question carefully, make sure you understand the question and then mentally see if you can answer the question. Next, go to the section of the lesson where the answer is given, and read over that section of the lesson again. Make sure that you completely understand the answer to the question. Then, close the book and write out the answer. Do not copy the answer from the book, but rather try to write the answer in your own words. If you find that you have difficulty and cannot answer the question, it is an indication that you need to study some more.

Many of the questions can be answered by a single word or by one or two words. Make your answers as brief and as direct as possible. Make sure that your answer actually answers the question asked. In some questions you will be asked to draw a schematic diagram or part of a diagram. Be sure you check these diagrams over carefully before you send in your answers for grading, because it is easy to make a mistake in drawing schematics.

Lesson Questions

Be sure to number your Answer Sheet B101.
Place your Student Number on every Answer Sheet.

Most students want to know their grades as soon as possible, so they mail their answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable. However, don't hold your answers too long; you may lose them. Don't hold answers to more than two sets of lessons at any time, or you may run out of lessons before new ones can reach you.

1. Two small balls of unknown material that are suspended near each other by threads are charged by being rubbed with a silk cloth. The balls then repel each other. Which one of the following statements will then be incorrect?
   (1) The balls both have a negative charge on them.
   (2) The balls both have a positive charge on them.
   (3) One ball has a positive charge, the other a negative charge.

2. Which does a negatively charged body have, a shortage or a surplus of electrons?

3. Draw a schematic diagram of a wire connected between the two terminals of a flashlight cell. Mark the polarity of the battery terminals and show by means of arrows the direction in which current will flow.

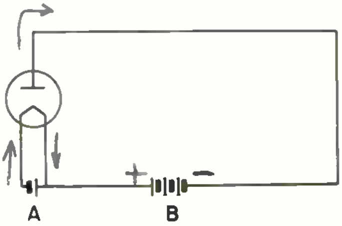
4. If we double the voltage applied to a circuit, what will happen to the current?

5. If you find that when you bring 2 magnetic poles together they attract each other, which one of the following statements is true?
   (1) The two poles must both be north poles.
   (2) The two poles must be south poles.
   (3) One pole must be a north pole and the other a south pole.

6. If a permanent magnet is held motionless inside a coil, will a voltage be induced in the coil?

7. How many flashlight cells would you have to connect in series to get 7.5 volts?

8. Will current flow from the filament to the plate in the circuit shown at right? Explain your answer. (Notice that the negative terminal of battery B is connected to the plate of the diode.)



9. Draw the schematic symbol of a modern triode tube and label the parts.

10. Draw the schematic symbol for a transistor and label each element with its full name.

HOW TO BUILD CONFIDENCE

Self-confidence--an active faith in your own power to accomplish whatever you try to do--is a personal asset which can do big things for you.

One thing which builds self-confidence is a successful experience. Each lesson completed with a passing grade is a successful experience which will build up confidence in you.

Little successes are contagious. Once you get a taste of success, you'll find yourself doing something successful every day. And before you realize it, your little successes will have built up to that big success you've been dreaming of. So--get the habit of success as fast as possible. Resolve to study every day, even if only for a few minutes.

Another confidence builder is a deep, firm faith in yourself--in your ability to get ahead. If you do believe in yourself and you are willing to back up this faith with good hard studying, you can safely leave the final result to itself. With complete confidence, you can look forward to an early success in electronics.

Act as if you could not possibly fail, and you will succeed!

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ACHIEVEMENT THROUGH ELECTRONICS

HOW ELECTRICITY IS PRODUCED FOR ELECTRONICS

B102

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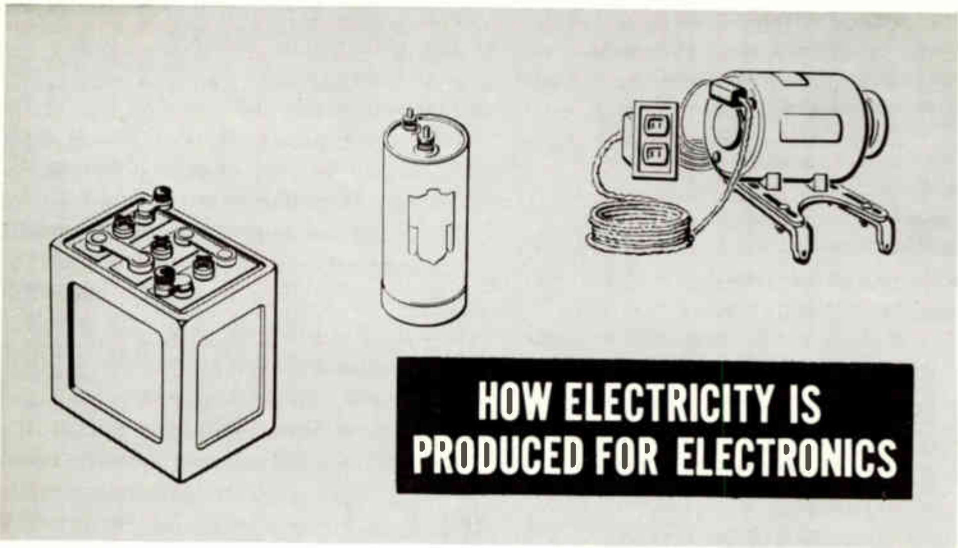
HOW ELECTRICITY IS PRODUCED FOR ELECTRONICS

B102

HOW ELECTRICITY IS PRODUCED FOR ELECTRONICS



Electronics is a term you will be meeting constantly from now on. Let us take time to see what we mean by the word "electronics." Originally the term electronics was applied only to devices using electronic tubes. However, in recent years the meaning has been broadened to include the whole field of electron behavior. Thus we can consider every application of electricity as part of the general field of electronics.

You have already seen many uses of electronic principles. You see them every day, for example, in your radio and television receivers.

The field of electronics is a growing field. The chances are that at this very minute while you are reading this lesson, engineers are working on new projects that will result in some new use of electronics. They may be working on some method of using electronics to improve on some process we are already using, or they may be working on something that is entirely new, something we have been unable to do before. You can be sure that we are going to see many new developments in electronics in the years to come.

In this lesson you are going to study some of the uses of electronics. We will cover only a few of the details, but you will learn enough to be able to understand these uses of electronics. In addition to learning something about these processes, you will learn more about the behavior of the electron.

The first use of electronics that you will study is in the power industry. Although this is often not considered part of the electronics industry, it is extremely important to electronics, because without economical power there would be very little use of electronics at all. This brief look at the power industry will help you in your study of other pieces of electronic equipment.

You will also learn more about electronics in radio. You will study several new components, and also you will learn how sound is sent through space by means of radio waves. This section on radio is important because the circuits you will study here are similar to ones you will find in radio, in television, and in other industrial applications.

You will also see how electronic principles are used in one branch of industry. Many industrial processes require large amounts of direct current.

It is much more convenient to generate and transmit alternating current than direct current. You will see how alternating current can be changed into direct current by means of electron tubes.

Finally, you will learn about pulse-type signals that are widely used in computers and television. You will learn the basic fundamentals of logic circuits that process these pulse signals in computers.

In studying the following sections of this lesson, it is important for you to understand the basic circuits and ideas presented. However, it is not necessary for you to remember all of the details of the various processes. As you complete a section of the lesson, answer the self-test questions at the end of the section. If you can answer these questions and remember the answers to them, then you should have no difficulty answering the questions at the end of the lesson. Between the self-test questions and the lesson questions, we will cover all of the important points in the lesson. Other details of the lesson will become more familiar to you as you go further in your course; these details will be covered again, and in many cases explained much more thoroughly than in this lesson.

If there are any basic circuits and ideas that you do not understand be sure to go over these points several times. If you need help be sure to take advantage of the NRI consultation service and write in requesting assistance. A thorough understanding of the basic fundamentals is absolutely essential; the more advanced lessons you will study later will be based on the fundamentals you will be learning in this and other basic lessons.

We have already mentioned that without economical electric power, there would be no electronics industry. In addition to economical power, we must have large amounts of power available.

The information on how electric power is generated is important to the radio-TV serviceman, the computer technician, the communications technician, and the industrial electronics technician. All may have occasion to service power-generating equipment. Even the radio-TV serviceman with only a small business may want to fix mobile equipment. There is more and more demand for people who can do repair work of this type, and in order to do such repairs one must be familiar with power-generating equipment.

There are two main sources of power in electronic equipment. One is batteries which you have already studied briefly. You will now look into batteries in more detail, and then go on to the study of generators to see how they operate and how the voltage generated is pictured.

Batteries

Batteries can be divided into two types: those containing primary cells and those containing secondary cells. Primary cells are cells that cannot be recharged. A flashlight cell is an example of this type. A secondary cell is a cell that can be recharged. The storage batteries used in automobiles are made up of secondary cells as are the rechargeable batteries used to operate portable television receivers designed for battery operation.

We mentioned previously that a battery is made up of two or more cells. But the word battery is also used to describe single cells, such as flashlight cells. Consequently, the word battery has come to mean anything from one cell up.

A basic knowledge of batteries is important to the electronics technician today because many of the devices he will encounter operate from batteries. For example, there are millions of portable radio receivers in use; almost all of these operate from batteries made up of cells like the flashlight cell. Portable television receivers which can be operated from either the power line or from a battery pack are becoming increasingly popular. These television receivers operate from small storage batteries that are similar to the storage batteries used in automobiles. Other types of batteries, such as the manganese battery and the mercury battery, are becoming increasingly important. In some ways these cells are similar to the flashlight cell, but they have a longer life. The chances are that they would replace the flashlight cell entirely except for the fact that they are more expensive.

A simple electric cell can be made by inserting two pieces of metal in an acid solution. The voltage produced by the cell will depend upon the metals used. For example, if one metal is zinc and the other copper, the cell voltage will be about 1.1 volts. If the copper electrode is replaced by a silver electrode, a voltage of about 1.5 volts will be produced. On the other hand, if magnesium is used as one electrode and gold as the other, a voltage of about 3.7 volts will be produced. Such a battery, while it has a relatively high voltage, isn't practical because of the cost of the gold and magnesium.

The cells we were speaking of contained acid in a liquid form. This type of cell has the disadvantage that the acid is easily spilled. A much more practical cell is the "dry cell", such as the flashlight cell, which we will now study in detail.

DRY CELLS

Dry cells are not really dry. The chemical mixture in the battery is actually quite moist, and when it becomes dry the battery is no longer usable. The name dry cell was given to these batteries because the chemical mixture was in the form of a paste rather than a liquid. The dry cell uses a carbon rod as the positive electrode and the zinc case as the negative electrode. The voltage of a cell of this type is 1-1/2 volts.

This cell is actually similar to the simple basic cells we mentioned earlier which contain two metals in an acid solution. In this case, one metal is zinc and the other is carbon. We do not often think of carbon as a metal, but actually it is midway between the metals and nonmetals, and in some cases acts like a metal and in other cases acts like a nonmetal. When used in a dry cell it acts like a metal.

The acid is in the form of a paste made up of ammonium chloride, powdered carbon and manganese dioxide. The ammonium chloride is the acid, the other two chemicals are added to improve the performance of the cell.

The construction of one type of dry cell that can supply current for a much longer time than a flashlight cell is shown in Fig. 1. This cell is similar to a flashlight cell except it is larger and has screw-type terminals to which the leads are connected. The metal case and carbon rod are often provided with screw terminals as shown here. Sometimes a plug type of connector is provided instead. A cell of this type can provide a much higher current than a flashlight cell, because it has much larger electrodes. However, the output voltage of the cell is the same as that of the flashlight cell (1-1/2 volts). In the early days of radio, four cells of this type, connected in series, were used to provide 6 volts to operate the filaments of the tubes in many radios.

Fig. 1. Construction of a dry cell.

Fig. 2. A square 1½-volt battery.

In addition to the round cell shown in Fig. 1, 1-1/2-volt cells are often made square. A square cell can often be fitted into a somewhat smaller place than a round cell, and therefore is particularly useful in portable equipment. A square cell is shown in Fig. 2. It would be more correct to call a square cell a battery because it is generally made up of four small round cells instead of one large cell. The negative terminals of all four cells are connected together and brought out to one common terminal which is the negative terminal of the battery. Similarly, the positive terminals of all four cells are connected together and brought to one common positive terminal.

As you learned earlier, this type of

connection is called a parallel connection and though there are four cells used, the output voltage from the battery is only 1-1/2 volts, the same as it would be if only one large cell were used. As we pointed out earlier, the advantage of this type of construction is that the four cells in parallel can supply more current than a single cell could alone. This is because the current the cell can supply depends primarily on the area of the positive and negative electrodes -- the carbon rod and the zinc case. Their area is greater when four cells are used in parallel than it would be if one cell of the same physical size were used. In addition, we pointed out that it is often more economical to use the four cells because the manufacturer may be making them in large quantities for other uses. This will bring the cost down so that it is more economical to use four of the smaller cells than it would be to use one large cell.

You already know that dry cells can be connected in series to provide more than the 1-1/2 volts available from the single cell. An example of this type of battery is shown in Fig. 3. This battery is designed to provide a voltage of 45 volts and is called a "B" battery. This type of battery was widely used in the early days of radio to provide the voltage between the plate and filament of the tubes in radio receivers. Later, smaller versions of the battery were used in portable receivers. Today, the battery itself is not as important as the lesson we can learn from it about the voltages between different points. The following section of this lesson is extremely important, read it several times to be sure you understand it completely.

"B" BATTERY

Fig. 3. A 45-volt battery made of dry cells connected in series.

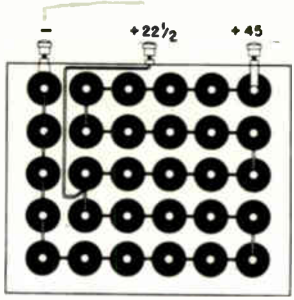


Fig. 4. How the dry cells in Fig. 3 are connected in series.

The battery shown in Fig. 3 is made up of thirty 1-1/2 volt cells connected in series as shown in Fig. 4. Notice that there are three terminals brought out of this battery. It is easy to see that the voltage between the two outside terminals should be 45 volts. There are thirty 1-1/2-volt cells, and 30 X 1-1/2 is 45. Now trace out the circuit between the negative terminal and the terminal marked +22-1/2 and you will see how we get this voltage. You will find that there are fifteen cells connected between these two terminals, and 15 X 1-1/2 is 22-1/2. Thus, if you need only 22-1/2 volts you would connect between the – terminal and the terminal marked +22-1/2.

Now look at the other half of the battery. What is the voltage between the terminals marked +22-1/2 and 45? By inspecting Fig. 4 you can see that there are fifteen cells connected between these two terminals. 15 X 1-1/2 is 22-1/2, and therefore there should be 22-1/2 volts between these two terminals. But which terminal is positive and which is negative? By looking at Fig. 4 again, you can find the answer to this question. Notice that the terminal marked +45 is connected to the positive terminal of one of the cells. The terminal marked +22-1/2 is connected to the negative terminal of the last cell in the group of fifteen cells connected between these two terminals. Therefore, this is the negative terminal and the +45 terminal is the positive terminal.

It may seem somewhat confusing at first that the terminal marked +22-1/2 can be both positive and negative. Let us see how this can be so. Starting with the negative terminal and looking toward the other two, you first see a group of fifteen cells and then a terminal. This terminal is positive compared to the negative terminal. We say it is positive with respect to the negative terminal. Then there is another group of fifteen cells and another terminal. This last terminal is even more positive with respect to the negative terminal. Now, if we started at the positive terminal and looked back through the battery we would see a group of fifteen cells and a terminal. This terminal is negative with respect to the positive terminal. We would then see an additional group of fifteen cells and another terminal, which is even more negative with respect to the positive terminal. We could, if we wished to do so, mark the battery as in Fig. 5. Notice that this is the same battery as the one in Fig. 4; we have simply marked the terminals differently. The voltage between the two outside terminals is still 45 volts, and the voltage between either outside terminal and the center terminal is 22-1/2 volts. In Fig. 4, we have considered the voltage at the negative terminal as zero and marked the other two positive with respect to it. In Fig. 5, we have considered the positive terminal as zero volts and marked the other two negative with respect to it. We could go one step further and mark the center terminal zero and the one outside terminal −22-1/2 volts and the other +22-1/2 volts with respect to the center terminal.

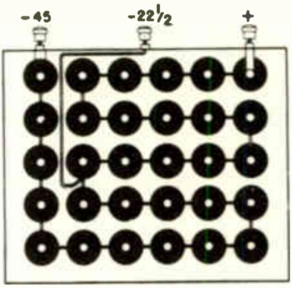


Fig. 5. The terminals of the 45-volt battery which are shown in Fig. 4 can be marked as shown.

You might wonder why there are all these different ways of marking battery terminals. The reason is that in electronic equipment one terminal of a battery is usually connected to a common or ground terminal in the equipment. Sometimes this terminal is the positive terminal of the battery, sometimes it is the negative terminal. It all depends on what the battery is to be used for. Usually the terminal voltages are marked with respect to the terminal that will be grounded in normal operation.

It is important to understand what is meant by a ground terminal or connection. In the early days of radio almost all radios were connected by a wire to a water pipe or to a pipe driven into the ground to improve reception. This was called a "ground" lead. One terminal of the "A" battery, the negative terminal of the "B" battery and the positive terminal of the "C" battery were all connected to the metal chassis on which the receiver was built, and the metal chassis was connected to the ground lead. Now the chassis in electronic equipment is called a chassis ground even though it may not be connected to an external ground connection at all. The negative side or terminal of the B supply is called B– ground or the common ground. In some equipment B– is connected to the chassis, but in other equipment it is not. When B– is connected to the chassis, we refer to both B– and the chassis as ground. When B– is not connected to the chassis, we refer to the chassis as a chassis ground and to B– as a floating ground. You will see these three expressions used frequently.

Remember that one terminal can be both positive and negative at the same time. In other words, one terminal might be positive when it is compared to another terminal, but negative when compared to a third. You will run into this situation over and over again.

Although a B battery is able to supply a much higher voltage than a single cell, the amount of current that can be taken from it is somewhat limited. If a B battery is used to supply a high current, it will soon be exhausted.

When you need a higher current than can be supplied by a single cell or battery, you can obtain it by connecting two or more batteries in parallel. When you connect two batteries in parallel, you connect the two negative terminals together and the two positive terminals together as shown in Fig. 6. This is the same type of connection that is used in the battery shown in Fig. 2, where the 1-1/2-volt battery was made from four cells connected in parallel. Of course, you can only do this if the batteries have the same voltage. When two similar batteries that are connected in parallel are connected to a circuit, each battery will supply approximately one-half of the current used in the circuit. This is more economical than taking the full current from one until it is exhausted and then taking the full current from another, because the batteries connected in parallel will usually last more than twice as long as a single battery.

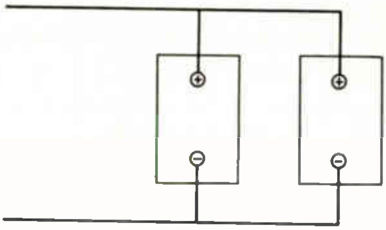


Fig. 6. Two batteries having the same voltage can be connected in parallel if a high current is required.

There are two big disadvantages of the dry cell. It has a fairly short shelf life and a rather large cell is required to supply a moderate current. The shelf life of a cell is the length of time it can be kept after it is made before it deteriorates to such an extent that its life is affected appreciably. When we say a dry cell has a short life we mean that it cannot be kept too long before it is put into service, otherwise it will not last long.

MERCURY CELLS

A cell that overcomes the two main disadvantages of the dry cell is the mercury cell. The voltage supplied by one of these cells is about 1.35 volts or about 1.4 volts depending upon the materials used in the cell.

There are two different types of mercury cells in use. One is a flat cell that looks something like a button, and the other is a cylindrical cell that more closely resembles a standard flashlight cell. The advantage of the button-type cell is that several of them can be stacked inside of one container to form a battery. A typical battery made of three flat cells is shown in Fig. 7. The battery is slightly smaller than a standard flashlight cell, but produces a higher voltage, has a longer life and can supply more current than a flashlight cell.

Fig. 7. The mercury battery shown is slightly smaller than a standard flashlight cell, but produces a higher voltage, and has a longer life than the flashlight cell.

Mercury cells were originally developed for use by the Armed Forces, but are now found in many pieces of portable equipment manufactured for civilian use. Their small size and long life make them ideal for use in transistorized equipment. Since transistors use only a small amount of current, transistorized equipment powered by mercury batteries can be operated for a long time before it is necessary to replace the batteries. When it is necessary to replace a mercury battery, the old batteries must not be disposed of by burning; these batteries will explode if they are thrown into a fire and might cause considerable damage or injury to someone nearby.

One other important point to remember about the mercury cell is that the small terminal on the top of the cell is the negative terminal. The case is the positive terminal. This is the opposite of the standard flashlight cell where the button on the top of the cell is the positive terminal and the case is the negative terminal.

MANGANESE BATTERIES

The big disadvantage of the mercury battery is that it is quite expensive. This has limited its use somewhat in entertainment type equipment, such as portable radios, etc. A battery that is not as expensive, but has many of the desirable characteristics of the mercury cell, such as long life, is the manganese cell. This cell is also often called the alkaline-manganese-zinc cell.

The manganese cell looks very much like a flashlight cell and is generally made in the same physical sizes as the small dry cells used for flashlights and portable radios. The voltage of a cell of this type is 1.5 volts so it can be readily substituted for a dry cell. A manganese cell can supply a certain value of current for much longer than the same size dry cell. Manganese cells are particularly useful in applications where the equipment is to be left on for a long time. Here their life will greatly exceed the life of a dry cell. However, in applications where equipment is operated intermittently for short periods, the manganese cell will outlast the dry cell, but the increase in performance may not be justified by the increased expense of the manganese cell.

LEAD-ACID BATTERIES

The storage battery used in automobiles is the best known example of a secondary cell. This type of cell has two groups of plates: one attached to the positive terminal and the other to the negative terminal. The plates are made of lead and fit together as shown in Fig. 8A. Between the plates are sheets of insulating material called separators, made either of porous wood or perforated wood or fiber glass. The separators prevent the plates from touching each other and destroying the cell. One of the sets of the plates is treated chemically to form an oxide of lead (a combination of lead and oxygen), and the two sets of plates with the separators between them are then placed in a container filled with a solution of sulphuric acid in water. The term "lead-acid battery" came about as a result of the use of lead plates in a solution of sulphuric acid.

The voltage in this type of cell is approximately 2 volts. Storage batteries used in modern automobiles are usually made of six cells connected in series so that the output voltage from the battery is 12 volts. Older automobiles used batteries in which three cells were connected in series to give an output voltage of 6 volts. A three-cell battery is shown in Fig. 8B.

To charge this type of battery, the battery is connected to a battery charger which simply applies a voltage slightly

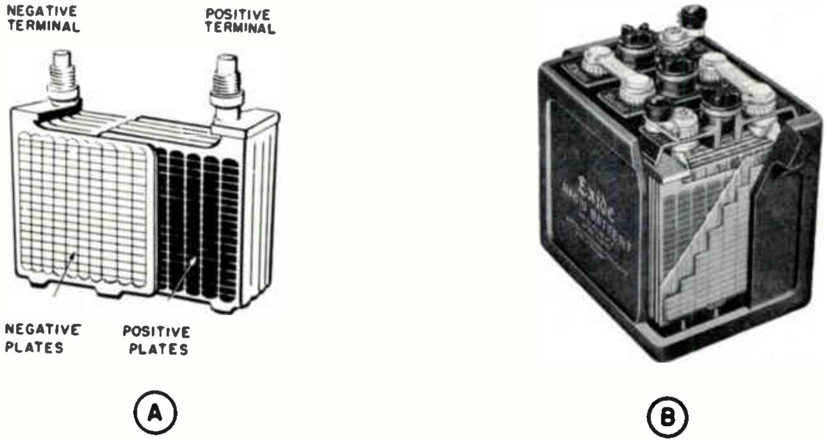


Fig. 8. (A) shows the construction of a storage battery; (B) shows a three-cell battery.

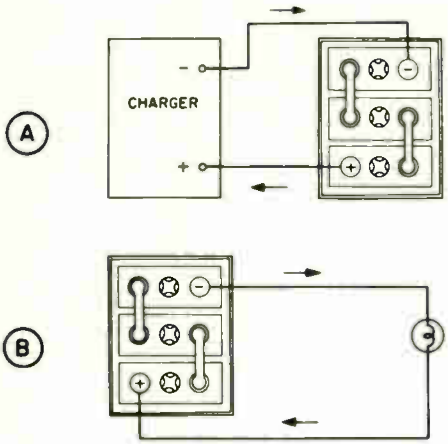


Fig. 9. (A) shows the direction current will flow when a storage battery is being charged; (B) shows the direction current will flow when the battery is supplying current.

higher than the battery voltage. The charger forces current through the battery as shown in Fig. 9A. This current causes a chemical change in the battery, and the electrical energy put in the battery is stored in it in the form of chemical energy. When the battery is connected to a circuit, the energy stored in the battery is released by the chemical action of the battery and current will flow in the circuit as shown in Fig. 9B.

Notice the direction of current in Figs. 9A and 9B. When the battery is being charged, the current is forced through the battery in the opposite direction to which it flows when the battery is supplying current. The storage battery can supply current for a much longer time than the average dry cell. When the storage battery is discharged and is no longer able to supply the current required by the circuit, the battery can be removed from the circuit and recharged by passing current through it in the opposite direction. Once the battery has been recharged, it can again be connected to the circuit and will supply current to the circuit.

In an automobile, the battery is usually connected to a generator. As long as the car is running at a reasonable speed, the generator is both charging the battery and supplying the current needed to operate the car. However, when the car is operating at a slow speed or when it is stopped, the generator is not turning fast enough to provide the electricity needed by the car and the battery supplies this energy. In the next section of this lesson you will study generators and you will see how they produce an electric current.

NICKEL-CADMIUM BATTERIES

There are two main disadvantages of the lead-acid storage battery. One disadvantage is that it has a somewhat limited life and the other is that it gives off hydrogen and oxygen when it is charged, and therefore the cell must be vented to allow these gases to escape. The hydrogen and oxygen given off from the battery come from the water in the cell and this water must be replaced periodically. As a result, the cell requires considerable maintenance.

A cell that overcomes this disadvantage is the nickel-cadmium cell. While the cell does give off gases when it is being charged, methods have been developed to take care of these gases so that the cell may be sealed. As a result, you do not have to add water or acid to the cell; the cell requires no maintenance other than to charge it when it becomes discharged.

The nickel-cadmium cell has an operating voltage of about 1.2 volts. While the cell cannot supply quite as much current as the same size lead-acid cell can supply, the fact that it will last almost indefinitely if it is cared for and that it can be sealed and requires no maintenance has made it ideally suited for use in operating portable electronic equipment. As more portable transistorized equipment is developed, it is likely that this type of cell will become more important to the electronics technician.

In charging both the lead-acid and the nickel-cadmium storage batteries or cells, the technician should follow the manufacturer's recommendations and avoid charging either type of cell at a higher rate. This is likely to cause excessive heat which can cause the plates in the cell to warp and touch. Once this happens, the cell is shorted and it is no longer usable.

SUMMARY

In this section of the lesson we have covered three important primary cells and two important secondary cells. We do not expect you to remember how these cells are made, but you should remember the voltage of each cell and remember their important characteristics. There may be occasions when you will want to substitute one type of cell for the other to obtain improved performance. In order to do this you must know the voltage supplied by each type of cell so that you can be sure that you will have the proper operating voltage for the equipment. You must also know something about their characteristics so that you will be able to select a suitable replacement that will result in improved performance.

The most important characteristic of the dry cell is its economy. Its disadvantages are its limited shelf life and its limited current capabilities.

The mercury cell has a much longer shelf life than a dry cell, and a given size mercury cell is capable of supplying a much higher current than a dry cell. That is to say, it can supply the same current as a dry cell for a much longer time. Mercury cells have a voltage of about 1.35 or 1.4 volts, depending upon the materials used in them. The disadvantage of the mercury cell is its cost.

The manganese cell can provide a given current for a much longer time than a dry cell can. Its shelf life is better than a dry cell, but not as good as a mercury cell. The output voltage of a manganese cell is about 1.5 volts.

The storage cell has the advantage that it can be recharged and used again. There are two important types of storage cells, the lead-acid cell and the nickel-cadmium cell. The lead-acid cell has a voltage of about 2 volts and the nickel-cadmium cell has a voltage of about 1.2 volts.

The advantage of the nickel-cadmium cell over the lead-acid cell is that it can be sealed and does not require the periodic maintenance that the lead-acid cell requires.

SELF-TEST QUESTIONS

(a) What is the output voltage of a dry cell?

(b) If fifteen dry cells are connected in series to form a battery, what would the output voltage be?

(c) If eight dry cells are connected in parallel to form a battery, what would the output voltage be?

(d) If six dry cells are connected in series to form a 9-volt battery and the negative terminal is marked with a minus sign and the positive terminal marked +9V, how would you expect a center tap terminal connected between the third and fourth cells to be marked?

(This is a difficult question - look at Figs. 4 and 5 before you make up your mind as to what the answer should be.)

(e) What are the two main advantages of the mercury cell over the dry cell?

(f) What is the output voltage of a mercury cell?

(g) What is the output voltage of a manganese cell?

(h) Since the manganese cell is a better cell than the dry cell, why hasn't it completely replaced the dry cell?

(i) Name two types of secondary cells.

(j) Which type of secondary cell provides the longest life, and the most maintenance-free performance?

Generators

Although batteries are very useful, their ability to supply large amounts of power is limited. If a battery, even a lead-acid storage battery, is called upon to supply large amounts of current, it will soon be exhausted and must be removed from the circuit and recharged. Even if storage batteries could supply the large amounts of electricity consumed daily by the average large city, we would still have to have some way of recharging the batteries. Thus, we would have a need for a device other than a battery that is capable of supplying large amounts of electricity.

You already know that if the magnetic field cutting through a coil is varied, a voltage will be induced in the coil. If the magnetic field is made to vary rapidly enough, the voltage will be induced continuously in the coil; this voltage can be connected to an outside circuit and current will flow through the circuit. This is the principle that is used in electric power generators.

Before studying generators, let us learn about two important kinds of current you will have to deal with: direct current and alternating current.

DIRECT CURRENT AND ALTERNATING CURRENT

The current supplied by a battery always flows from the negative terminal of the battery through the external circuit and back to the positive terminal of the battery. The current always flows in one direction. We call this kind of current ***direct current.*** We usually abbreviate this ***dc.***

The voltage supplied by a battery that causes a direct current to flow is referred to as a ***dc voltage.*** The expression dc voltage means that the voltage causes a direct current to flow. This means that the polarity does not change. In other words, on a battery, one terminal is always the negative terminal and the other terminal is always the positive terminal. We say that the terminals always have the same polarity -- the polarity of the terminals does not change.

A dc generator is a device that generates a direct current. In other words, the current coming from the generator always flows in the same direction. This means that the terminals of the generator must always have the same polarity; one terminal will always be the negative terminal and the other terminal will always be the positive terminal.

Besides direct current, there is another important type of current with which you must be familiar. This type of current is called ***alternating current*** or simply ***ac.*** Alternating current differs from direct current in that its direction is continually changing. The current flows first in one direction and then in the opposite direction. This reversal of current occurs many times a second. The current supplied to your home is alternating current. The voltage that produces an alternating current is called an ***ac voltage.*** In order to produce a flow of alternating current the polarity of the terminals of the device causing the current flow must be continually reversing. In other words, when the current is flowing in one direction, one terminal must be negative and the other positive. When the current flows in the opposite direction, the polarity of the terminals must reverse so that the terminal that was the negative terminal must become the positive terminal and the terminal that was the positive terminal must become the negative terminal.

While alternating current cannot be used to operate such electronic devices as tubes and transistors, it has many useful applications; indeed our modern industries depend upon large amounts of alternating current being readily available.

Now we will go ahead and learn how a simple generator operates and at the same time learn more about alternating current and ac voltage.

A SIMPLE GENERATOR

A simple generator capable of generating electric power can be built as shown in Fig. 10. This generator consists of a single-turn coil placed between the poles of a magnet. As the coil is rotated, it will cut through the magnetic lines of force flowing from the north pole to the south pole of the magnet and a voltage will be induced in the coil. The amount of voltage will depend upon the number of magnetic lines being cut by the coil as it rotates. This in turn will depend upon the strength of the magnetic field and upon the speed at which the coil is rotated.

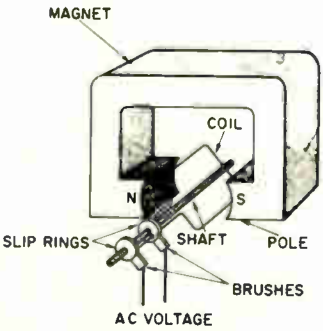


Fig. 10. A simple ac generator.

First, let us consider the voltage that will be produced by a generator of this type. When the coil is in the position shown in Fig. 11A, the movement of the coil is parallel to the lines of force flowing from the north pole to the south pole of the magnet. They are moving along the lines of force and are not cutting through any of the lines of force. You will remember that in order to induce a voltage in a coil, the turns of the coil must be cut by magnetic lines of force. In Fig. 11A, the coil is moving along the lines of force and not cutting through them. There will be no voltage induced in the coil when the coil is in this position.

When the coil moves counterclockwise to the position shown in Fig. 11B, it will still be moving almost parallel to the lines of force. However, it is moving at a small angle to these lines of force and therefore it will cut through some of them and there will be some voltage induced in the coil. When the coil moves down to the position shown in Fig. 11C, it will be cutting more lines of force because it is moving at a sharper angle to them and a somewhat higher voltage will be induced in the coil. Finally when it reaches the position shown in Fig. 11D, it will be moving directly perpendicular to the lines of force and will be cutting through them at maximum speed, and the voltage induced in the coil will reach its highest

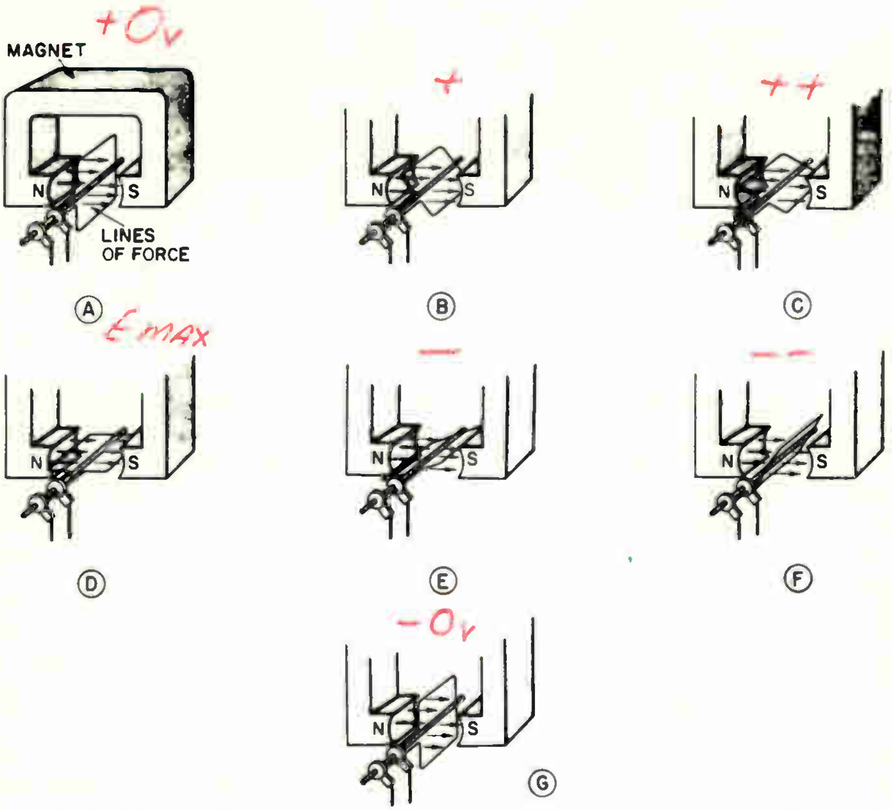


Fig. 11. In the illustration, the coil is rotating counterclockwise. The voltage produced by this generator depends upon the movement of the coil in relation to the magnetic lines of force.

value. As the coil moves down to the positions shown in Figs. 11E and 11F, it will be cutting fewer and fewer lines of force until it finally reaches the position shown in Fig. 11G. Once again the coil will be running parallel to the lines of force and no voltage will be induced in the coil.

HOW VOLTAGES ARE PICTURED

You will remember that when we discussed the batteries shown in Figs. 4 and 5 we said that one terminal of the battery could be considered as zero voltage and the voltage at the other terminals marked in reference to this terminal. You can do the same thing with a generator. You can use one lead as the ground or common lead and measure the voltage at the other lead as either positive or negative with respect to the common lead.

If we assume that one lead is a common or ground lead, we can conveniently represent the voltage at the other lead by a graph. A graph is merely a simple way of presenting information in the form of a picture. In Fig. 12A, you will notice a

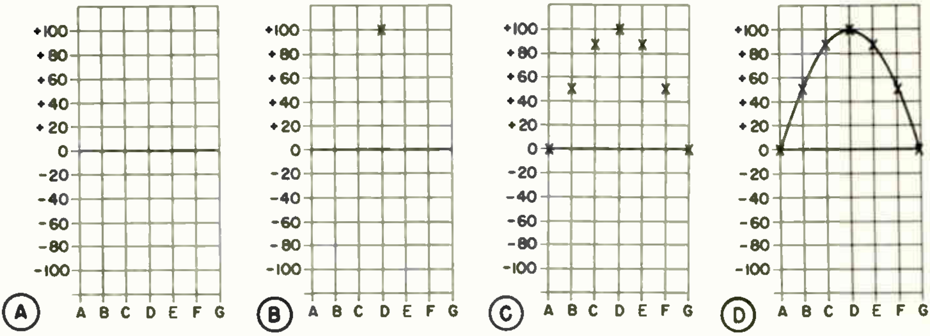


Fig. 12. Construction of a graph of the voltage produced by the generator in Fig. 11.

horizontal line which is marked zero running through the center of the graph. This is the zero voltage line which represents the voltage of the ground or common lead. The horizontal lines above this line represent positive voltages, and the lines below the zero line represent negative voltages. The vertical lines represent the positions .of the coil shown in Fig. 11.

Let us assume that at the instant the coil is in the position shown in Fig. 11D, the voltage generated is 100 volts. If the voltage is 100 volts positive with respect to the common terminal, we would place a mark (X) on the graph at the point where the +100 volt line crosses the vertical line running through D, as shown in Fig. 12B. Similarly the voltages that are present at the remaining points would be marked on the graph. This would look like Fig. 12C. The only step left is to draw a smooth curve joining all these points as shown in Fig. 12D. This curve represents the voltage generated by the generator through one half turn.

When the coil is rotated through the remaining half turn, the polarity of the voltage produced will be reversed. In other words, the voltage will now be negative with respect to the ground terminal because the coil will now be cutting through the magnetic lines of force in the opposite direction. If we complete the

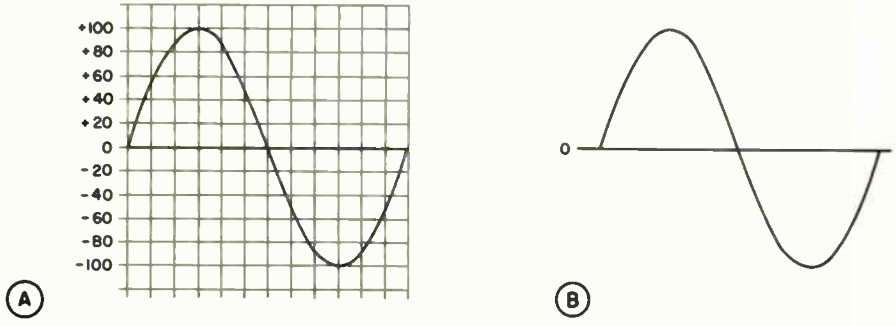


Fig. 13. The appearance of the output voltage produced by the generator as it travels through one complete turn.

drawing to show what the voltage will look like during the other half turn, the picture would look like Fig. 13A. For convenience, if we leave the horizontal and vertical lines of the graph off, we can get a better look at the shape or appearance of the output voltage as in Fig. 13B. This is called a waveform.

This is how the ac voltage supplied by the power company may be represented. It is called a sine (pronounced sign) wave.

The voltage represented by one complete turn of the coil in the magnetic field is called a cycle. The power supplied by most power companies in this country is 60-cycle power. When we say 60-cycle, we mean 60 cycles per second. In other words, the voltage goes through 60 cycles each second, like the one shown in Fig. 13. This is called the "frequency" of the ac voltage. To make the generator produce this type of voltage, it would have to be turned at a speed of 60 revolutions per second, which is 3600 revolutions per minute. The part of the cycle above the line is called a half cycle, and it is referred to as the positive half cycle. The part of the cycle below the line is also called a half cycle, and it is referred to as the negative half cycle.

You will also see the term Hertz, abbreviated Hz, used to designate the frequency of an ac signal. Hertz and cycles per second mean exactly the same thing and you will see these expressions used interchangeably. Hertz is the preferred term, but you will see cycles per second used almost as often. Just remember when you see the expression 60 Hz signal, we are referring to an alternating voltage or current that completes 60 cycles per second.

The voltage generated by this generator with only a single-turn coil would be extremely low, even with a very strong magnetic field. However, we can obtain a higher voltage simply by putting more turns of wire on the coil. Ten times as much voltage would be induced in a ten-turn coil as in a single-turn coil. If one-tenth of a volt is induced in a single-turn coil, one-tenth of a volt will be induced in each turn of the ten-turn coil. These voltages will be induced in series with each other so that the total voltage available at the output terminals of the coil will be 1 volt. By putting 100 turns on the coil, we could get 10 volts; by putting 1000 turns on the coil, we could get 100 volts.

Thus, by putting the proper number of turns on the coils of a generator we can generate any required voltage.

DC GENERATORS

Instead of using a permanent magnet such as the one shown in Fig. 10, a practical generator would use an electromagnet to supply the magnetic field. The current required to operate this electromagnet can be obtained either from the generator itself or from another generator. However, it must be dc. The voltage generated by the generator we have discussed is ac. Now let us look into the generator further and see how we can obtain dc instead of ac.

In an ac generator such as the one described, the ends of the coils are connected to slip-rings. By means of contacts riding on the slip-rings (which are called brushes), we could take the ac voltage off the generator. However, if, instead of using two slip-rings, we use a

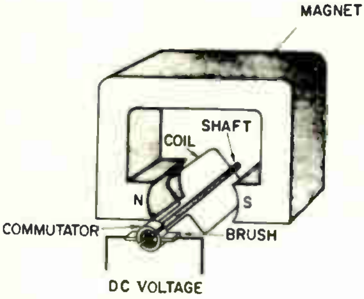


Fig. 14. A simple dc generator.

commutator, as shown in Fig. 14, we can obtain dc. A commutator is similar to a slip-ring except that it is split in half and the two halves are insulated from each other. The brushes are placed so that when the coil is going through the first half revolution, one brush will be connected to one section of the commutator and the other brush will be connected to the other section. When a coil starts to go through the second half revolution, the brushes will be connected to the opposite section; the one that was connected to the first section will then be connected to the second section, and the one that was connected to the second section will then be connected to the first section and current will always flow through the external circuit in the same direction, as shown in Fig. 15. As a result, at the output we will have a voltage like that shown in Fig. 16.

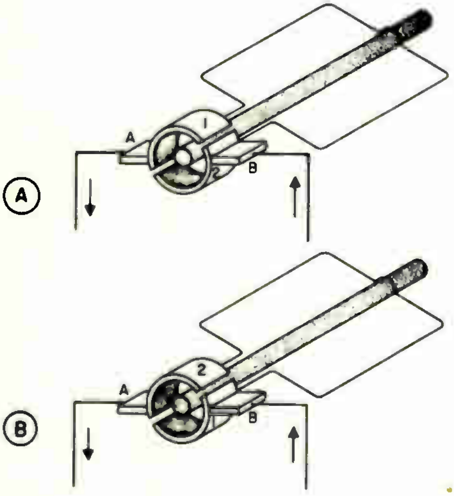


Fig. 15. In (A), section 1 of the commutator is negative, and section 2 is positive. In (B), section 1 is positive, and section 2 is negative. This means that brush A is always connected to the negative section of the commutator and brush B to the positive section, and current flows in only one direction.

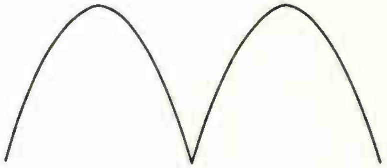


Fig. 16. Output of a simple dc generator.

Here we have essentially the same wave shape as we had in Fig. 13, except that the half of the cycle that was previously negative and drawn below the line has now been reversed by the automatic reversing of the connections to the coil performed by the commutator and brushes.

A voltage like that shown in Fig. 16 is called pulsating dc. It is dc inasmuch as the current that flows as a result of this voltage will always flow in one direction. However, since the voltage varies, the current varies; it will flow in pulses and actually drop to zero twice through each revolution of the coil. This can be used in some applications but it is not what we call pure dc, like the dc supplied by a battery.

As in the case of the ac generator, the output voltage from a dc generator with only a single turn would be extremely

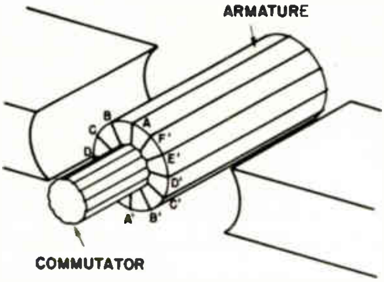


Fig. 17. The armature of a dc generator with 6 series-connected coils.

low – too low to be usable. However, by winding several turns on the coil, a higher voltage can be obtained. This will still provide a pulsating type of dc like that shown in Fig. 16.

A better arrangement is shown in Fig. 17. Here, there are a number of coils on an iron form called an "armature." The coils are in different positions around the armature. In the position shown, coil A-A′ will not cut any lines of force and therefore there will be no voltage induced in it. The coil B-B′, however, is cutting a few lines of force and some voltage will be induced in it. Coil C-C′ is cutting still more lines of force and a somewhat higher voltage will be induced, and coil D-D′ is cutting directly across the lines of force and the maximum voltage will be induced in it. These coils are all connected in series and brought out to connections on the commutator. Two brushes are used on the generator, and the output voltage from this type of machine will be nearly constant. This is because there will always be one coil either in or close to each position shown in Fig. 17. The voltage produced by the generator will be the voltage of all the coils in series. While some of the coils are producing very little voltage, the coils near the position D-D′ will produce considerable voltage. The commutator used with this type of generator would have twelve sections instead of two, as is the case in the generator with only one coil. There will be some fluctuation in the voltage so that the output voltage will look like Fig. 18 as the generator goes through one revolution. Notice that with this type of generator, instead of two big half cycles, an almost constant value of dc is obtained.

Fig. 18. Only a small ripple will be noticeable in the output of a dc generator having 6 coils and 12 commutator sections.

AC VALUES

Now look back at the ac cycle shown in Fig. 13. Notice that at the start of the cycle the voltage is 0. When the coil has rotated through one quarter of a turn, the voltage has built up to a maximum value; when the coil has gone through one-half a turn, the voltage is back to zero again. At three-quarters of a turn, the voltage has reached a maximum value with the opposite polarity and finally at the end of the cycle, the voltage is back to zero. The end of this cycle is actually the start of the next cycle. The voltage reaches a maximum value twice in each cycle, and it drops to zero twice in each cycle.

Let us see how we measure ac. When we talk about a dc current and we say that the current flowing in the circuit is 1 amp, we mean that a certain number of electrons are flowing past a given point in the circuit. This same number of electrons continues to flow as long as the current in the circuit is 1 amp. However, what happens when we're dealing with ac? Since the voltage reaches a maximum twice each cycle and falls to zero twice each cycle, the current must also have two maximums in each cycle and fall to zero twice each cycle. Therefore, the number of electrons flowing in the circuit is not constant; in fact it is continually changing as the ac voltage goes through its cycle.

To overcome this difficulty, we measure ac in terms of equivalent dc. When we say that the ac current flowing in the circuit is 1 amp, we mean that the current is the equivalent of 1 amp of dc. In other words, if a dc current of 1 amp flows through a heating element such as found in an electric iron or toaster, a certain amount of heat will be produced. When the ac current flowing through the same heating element produces the same amount of heat, we say that the ac current is 1 amp.

The same system is used to measure ac voltage. If a dc voltage of 100 volts is required to force the current of 1 ampere through a circuit made up of a resistance, the ac voltage that will force an ac current of 1 amp through the same resistance is said to be 100 volts. This is called the ***effective*** or ***rms voltage*** and it will cause an ac current to flow that will produce the same heating effect as the equivalent amount of direct current.

From looking at an ac voltage cycle, it is quite obvious that the voltage must be greater than the effective value during part of the cycle and less than the effective value during the remainder of the cycle. The maximum value that the ac voltage reaches during a half cycle is called the ***peak voltage***. The peak voltage is approximately 1.4 times the effective voltage. Each peak is 1.4 times the effective voltage, and the voltage between the two peaks will be 2.8 times the effective voltage. This voltage is called the ***peak-to-peak voltage***. Fig. 19 shows an ac voltage of 100 volts. The peak value is 140 volts, and the peak-to-peak value 280 volts. Study this figure to be sure you understand what the terms mean.

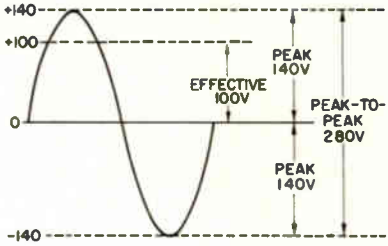


Fig. 19. AC waveform showing effective (rms), peak and peak-to-peak voltages.

It's important to remember when we are talking about ac voltages that unless we specifically refer to the peak or peak-to-peak voltages, we are talking about effective voltages; in other words, the ac voltages that will produce the same effect as the equivalent dc voltage. Also remember that the peak or greatest voltage reached during a half cycle will be 1.4 times as great as the effective voltage, and that the peak-to-peak voltage will be 2.8 times the effective voltage. You will run into the terms "peak voltage" and "peak-to-peak voltage" as well as the expression "effective voltage" many times during your career in electronics. Knowing the peak value of an ac voltage is often very important.

A good example of how high the peak voltage in a circuit may be is the voltage supplied in most homes in this country. The average power company supplies a voltage somewhere between 115 and 120 volts, 60 Hertz ac for lighting and general domestic uses. This is the effective value of the voltage. Let us assume that the voltage supplied to your home is exactly 120 volts. What is the peak voltage reached during each half cycle? It will be 1.4 X 120, which is 168 volts. In other words, twice during each cycle the actual voltage between the two power leads connected to each electric light and appliance in your home reaches a value of 168 volts. Twice during each cycle the voltage also drops to zero.

The net effect of this ac voltage is the same as supplying a dc voltage of 120 volts to the electric lights. The peak-to-peak voltage supplied to your home will be 2.8 X 120 volts or 336 volts!

THE IMPORTANCE OF AC

You may wonder why we have gone into so much detail in describing alternating current. Alternating current is important not only because it is the type of power supplied by the power companies, but also because ac signals are used throughout the whole electronics industry. The sound that comes from the loudspeaker in your radio or your television receiver and the sound from your telephone are produced by ac signals having a frequency not too much higher than the power line frequency. The radio waves that travel through space are actually ac signals of a much higher frequency. Signals used in many industrial applications are ac signals.

SUMMARY

We have covered a great deal of material in the preceding sections. There are several important things that you should remember. First, remember what an ac cycle looks like. Also remember that this ac voltage is called a sine wave.

Remember that when we speak of ac voltage and current we are speaking of the voltage and current that will produce the same effect as the equivalent values of dc. Remember that the peak value of the ac cycle is 1.4 times the effective value, and the peak-to-peak value is 2.8 times the effective value.

SELF-TEST QUESTIONS

(k) What are the two kinds of current that the electronic technician must know about?

(l) What do we call the voltage that produces a current that flows in only one direction?

(m) What is the name given to a voltage that causes current to flow first in one direction and then in the other direction many times in a second?

(n) What is the name given to the ac voltage wave supplied by the power company?

(o) What is a cycle?

(p) What do we mean by 60 cycles per second (60 Hertz)?

(q) What is the name given to the device on a dc generator that is used to reverse the connections of the coil to produce dc instead of ac?

(r) What type of current is produced by a simple dc generator such as the one shown in Fig. 14?

(s) What do we mean when we say that the ac current is 1 amp?

(t) If we say the ac voltage is 100 volts, do we mean the effective or the peak value of the ac voltage is 100 volts?

(u) If the rms voltage is 200 volts, what is the peak value of the voltage?

Electronics in Communications

Radio waves are sine waves like the one shown in Fig. 13. They are similar to the 60 Hertz ac power waves. The only difference is in the frequency of radio waves. The lowest frequency radio waves have a frequency of about 15,000 Hertz. We usually use kilohertz instead of Hertz when speaking of radio waves around this frequency. -- one kilohertz equals one thousand Hertz. Therefore, 15,000 Hertz is equal to 15 kilohertz (kHz). This is a very low frequency radio signal; there are only a few very high-powered stations operating on such low frequencies. They are used mostly by government services for world-wide communications.

The standard radio broadcast stations operate on frequencies between 550 kHz (550,000 Hertz) and approximately 1,700 kHz (1,700,000 Hertz). This group of frequencies is called a band; in this case, the broadcast band. The word band when it is used this way means nothing other than a group of frequencies.

Needless to say, ac signals of such high frequencies cannot be generated by means of mechanical generators such as those used to produce 60-cycle power voltages and current. These ac signals must be generated by electronic devices such as vacuum tubes and transistors.

We mentioned that the frequency of radio signals is often expressed in kilohertz rather than in Hertz. A kilohertz is equal to 1,000 Hertz. However, many broadcast services operate on such high frequencies that even the kilohertz is not large enough to provide a convenient method of expressing their frequency; so in addition to the kilohertz we use the megahertz. The megahertz is 1,000,000 Hertz and it is abbreviated MHz. There are 1,000 kilohertz in a megahertz. The standard broadcast band is 550 kHz to 1700 kHz. This can also be expressed as .55 MHz and 1.7 MHz. TV stations operate up in the megahertz region. Channel 2, the lowest TV channel, occupies the band of frequencies from 54 MHz to 60 MHz. Channel 13 occupies the band of frequencies from 210 MHz to 216 MHz. These channels are referred to as the vhf (very high frequency) TV channels. The FM broadcast band, which is located between channels 6 and 7, occupies the band of frequencies from 88 to 108 MHz.

TV channels 14 through 83 are referred as the uhf (ultra high frequency) channels. Channel 14 occupies the band of frequencies from 470 MHz to 476 MHz and Channel 83 occupies the band of frequencies from 884 MHz to 890 MHz.

Now let us look at some parts of a radio system. We will briefly describe a radio transmitter and a receiver. Let us look at the transmitter first.

THE RADIO TRANSMITTER

Radio transmitters are actually made up of a number of sections, each designed to do a specific job. Let's discuss some of the more important sections of a typical transmitter.

The sound signal to be transmitted starts in the microphone. There are a number of different types of microphones in use. We will look at one of the simpler types. Before we discuss the microphone, let's learn a little about sound.

Sound is a vibration set up in air or some other medium. The key you strike on a piano is connected to a hammer, which strikes a string that is tightly stretched on a frame. The string begins to vibrate and sets the air surrounding it into vibration. The frequency at which the string vibrates will determine the tone that you hear. Similarly, when we speak, the speech muscles in our throat set the air in our throat into vibration. This vibration is projected from our mouth and nose, and the vibration travels through the air. However, instead of producing a single frequency, our voices are actually quite complex and may produce vibrations of many frequencies, causing the different tones by which we can distinguish the voice of one person from that of another.

Microphones. A simple microphone is shown in Fig. 20. This microphone consists of a coil and a magnet and a flat metal disc which is called a diaphragm. Fastened to the diaphragm is a small light coil form on which a coil is wound. The coil is placed between the poles of a permanent magnet. When you speak in front of the microphone, your voice sets the air into vibration. The vibrating air will cause the diaphragm to vibrate. Since the diaphragm is connected to the coil, the coil will vibrate between the poles of the magnet. You already know what will happen when a coil is moved in a magnetic field; the turns of wire on the coil will cut through the magnetic lines of force, and voltage will be induced in the coil. If this coil is connected to an external circuit, there will be a current flow through the circuit. The frequency of the current will depend upon the frequency at which the diaphragm and coil vibrate. This in turn will depend upon the frequency at which the air is vibrating, which in turn depends upon the vibrations set up by the vocal muscles in the throat of the person speaking in front of the microphone.

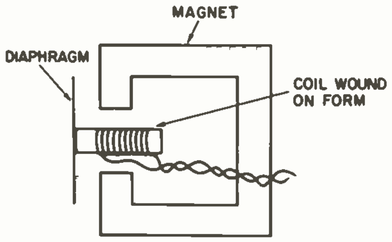


Fig. 20. A simple dynamic microphone.

This electrical signal produced by the microphone is called an audio signal or audio voltage. The word audio is used to designate electrical signals in the frequency range of sound. An audio voltage or signal is the electrical equivalent of sound.

An Audio Amplifier. In a typical transmitter the output of the microphone is fed to an audio amplifier. The audio voltage is fed to a vacuum tube or a transistor that will amplify the signal so that a much stronger signal will appear in the output circuit of the tube or transistor. The amplified signal will be just like the signal generated by the microphone, but it will be stronger. A tube or transistor along with its associated parts is called a stage. A stage used to amplify an audio signal is called an audio stage.

In a typical transmitter, the audio signal produced by the microphone will be amplified by a number of stages in order to build up the strength of the signal until it is hundreds of times stronger than the original signal produced by the microphone. The signal is first fed to one stage where it is amplified and then on to a second stage where it is amplified still further and on to a following stage and so on until its strength has been built up to the desired level. The amplified signal, however, will have exactly the same frequency and characteristics as the original signal produced by the microphone.

The microphone and the audio amplifiers in a transmitter are called the audio section. This is often abbreviated af (audio frequency) section. Another important section of the transmitter is the radio frequency section -- this is abbreviated rf section.

The RF Section. The rf section of a transmitter is made up of a number of separate stages. The first stage is the stage that actually generates the radio frequency signal. This stage is called the oscillator stage. The oscillator stage is carefully designed to produce a signal of the desired frequency. The signal from the oscillator stage is then amplified by additional stages which are called rf power amplifier stages. These stages build up the strength of the radio frequency signals generated by the oscillator so that the signals will be strong enough to travel through space from the transmitter to the receiver.

In one of the radio frequency stages of the transmitter, the audio signal is superimposed on the radio frequency signal. This is called modulation. The audio signal is the modulation signal and the rf signal is the modulated signal.

In a radio system of this type, the modulation signal varies the amplitude or strength of the rf signal. This type of modulation is called amplitude modulation and is abbreviated AM. In some transmitters the modulated signal is then fed directly to the antenna, but in others it is amplified further and then fed to the antenna.

The modulated rf signal from the transmitter is fed through a cable or wire, called a transmission line, to the antenna. The transmission line is something like the power lines that are used to bring the power from the power-generating station to your home. They simply carry the power from the transmitter to the antenna.

The antenna at a radio station is simply a length of wire or a tower to which the transmission line is connected. When the radio frequency signal is fed to the

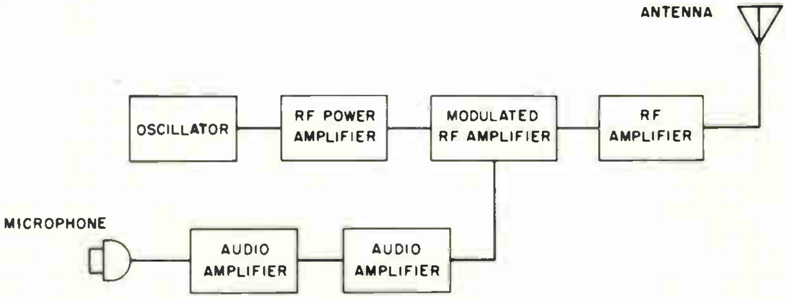


Fig. 21. A block diagram of a simple transmitter.

antenna, the rf signal sets up a current in the antenna which produces a magnetic field and an electric field surrounding the antenna. These fields travel out in space from the antenna and carry the signal from the transmitting antenna to the receiving antenna.

A simplified diagram of a radio transmitting system is shown in Fig. 21. This type of diagram is called a block diagram. It is a simpler way of representing the various stages or sections of a piece of electronic equipment than showing the complete schematic diagram. We will use this type of diagram frequently because it enables us to give an overall picture of the various stages of a piece of electronic equipment without going into all the details of the circuitry. You will find later that the circuits used in the various stages follow certain basic patterns. In other words, there is little difference in the circuits used in the individual stages; the difference is the manner in which the stages are used.

Notice that the sound signal is generated by a microphone and fed to the audio amplifier stages. At this same time the rf signal is generated by an oscillator and amplified by rf power amplifier stages. In the third rf stage, the rf signal is modulated by the audio signal and the modulated signal is then amplified by the last stage in the transmitter. This stage is called the final amplifier or simply the final because it is the last rf amplifier stage in the transmitter. The signal from the final is then fed through a transmission line to the transmitting antenna.

This brief description of Fig. 21 is all you need to know about radio transmitters at this time. However, you should understand in general terms what is done in a transmitter; it will be helpful to you, even though you may never work on a radio transmitter. Notice the symbols used in Fig. 21 for the microphone and the antenna. Remember these symbols; you will see them frequently in future lessons.

THE RECEIVER

The job that the receiver has to perform is exactly the opposite of the job the transmitter has to perform. The transmitter must take the sound and convert it to an electrical signal, which is the audio signal, and then superimpose the audio signal on an rf carrier signal. The receiver must take the rf carrier and remove the audio signal from it and then convert the audio signal back into sound.

In spite of the fact that the receiver must perform the opposite tasks from those performed by the transmitter, there are many similarities between a transmitter and a receiver. A transmitter has rf amplifiers, so do many receivers. The transmitter has audio amplifiers, so do receivers. The transmitter has a stage in which modulation occurs -- the receiver has a stage in which demodulation occurs. Demodulation is sometimes called detection; it is the recovery of the audio signal from the modulated signal. You will see later that there is a great deal of similarity between the operation of the stage in which modulation occurs and the stage in which demodulation occurs. The transmitter has a microphone which converts the sound into an electrical signal; the receiver has a speaker which converts the electrical signal to a sound signal. Even though the microphone and speaker perform opposite tasks, there is a great deal of similarity between the two.

Now let's look at a simple receiver system. Modern receivers are somewhat more complicated than the one we will describe, but nevertheless millions of receivers like this one have been made.

The Antenna. The radio receiving antenna is a much simpler device than the transmitting antenna. The signals transmitted by modern broadcast transmitters are so strong that only simple receiving antennas are needed. A simple outside antenna may be made from a wire 25 to 50 feet long mounted between two poles. Most modern radio receivers do not need any outside antenna at all. An indoor antenna made of a coil wound on a powdered iron core is called a ***loopstick***. It is mounted in the rear of the receiver, inside of the receiver cabinet. This is all the antenna that is needed to provide satisfactory reception on local broadcast stations. A loopstick mounted in the rear of a receiver is shown in Fig. 22.

The RF Amplifier. The signal picked up by the receiving antenna is quite weak even if the station being received is a fairly strong local station. Before the signal can be used it must be amplified. This amplification is usually carried out in a stage called an rf amplifier. It is quite similar to the rf amplifier in a transmitter, except it is called an rf voltage amplifier (in a transmitter it is called an rf power amplifier). The rf amplifier in the receiver is designed to increase the strength of the signal voltage picked up by the antenna.

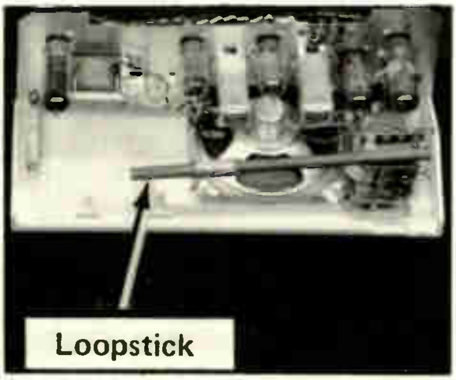


Fig. 22. Loopstick mounted in the rear of a receiver.

The Demodulator. The amplified signal from the rf amplifier is fed to a stage called the demodulator or detector. This stage separates the audio signal from the rf signal. The rf signal is called the carrier; it carries the audio signal from the transmitter to the receiver. However, it serves little or no useful purpose in the receiver. In the detector stage, the rf signal is separated from the audio signal. The rf signal is discarded so that the signal at the output of the detector is an audio signal. This audio signal is exactly like the audio signal that was originally produced by the microphone in the transmitter.

The Audio Amplifier. The signal at the output of the detector is still a weak signal. Before it can be used to operate a loudspeaker, the strength of this signal must be increased. It is increased by feeding the signal to an audio amplifier, which is similar to the audio amplifier in a radio transmitter. The signal at the output of the audio amplifier is identical to the signal at the input, but much stronger.

The Speaker. A speaker is not very different from a microphone. In fact, sometimes speakers are used as microphones in intercommunications units such as between two offices.

A sketch of a simple speaker is shown in Fig. 23. Notice that the speaker has a magnet like the microphone. Between the poles of the magnet is a coil, and the coil

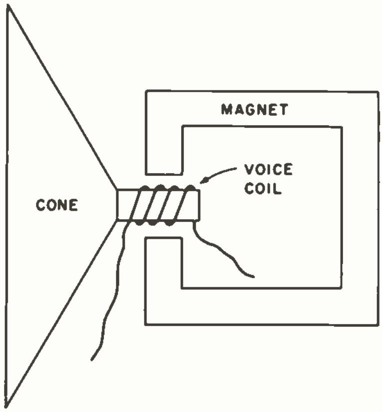


Fig. 23. A simple pm dynamic speaker.

is connected to a diaphragm. However, instead of having a flat diaphragm as in the microphone, the diaphragm is cone-shaped and in a speaker it is called the cone. The cone is fastened to the coil.

When the varying current from the audio amplifier is fed to the coil in the speaker, a varying magnetic field is produced. Depending on the polarity of the field produced by the current flowing in the coil, the field may either aid or oppose the magnetic field produced by the permanent magnet. Since the audio signal is being fed to the speaker, it is actually an ac signal. The polarity of the magnetic field produced by the coil will sometimes aid and sometimes oppose the permanent magnet field. This varying effect will cause the coil to vibrate in and out. Since the coil is fastened to the cone, the cone will vibrate in and out with the coil. The rate of vibration will depend upon the frequency of the audio signal.

The vibrating cone will set the air in front and in back of the cone in motion. The air will vibrate at the same frequency as the cone vibrates. Since the cone is vibrating at the frequency of the original sound signal produced by the microphone, the air around the speaker will be set into vibration at the same frequency. The effect of setting this air into vibration is exactly the same as setting the air into vibration with your vocal chords by speaking. The vibration will be heard as sound, and the sound will be at the same frequency and tone as the original sound that was first uttered in front of the microphone.

The operation of modern speakers is similar to that of the speaker shown in Fig. 23. This type of speaker with a moving coil is called a dynamic speaker. Modern dynamic speakers have a permanent magnet like the one we have shown, and this type is called a permanent magnet dynamic speaker and is usually abbreviated simply a pm speaker. Another type of dynamic speaker uses an electromagnet instead of a permanent magnet. This small coil placed between the poles of the magnet is called the voice coil. Usually the voice coil is wound on a small lightweight form.

The magnets used in pm speakers are strong permanent magnets made of alnico. You will remember that alnico is an alloy of aluminum, nickel, and cobalt which can be used to make extremely strong permanent magnets.

TELEVISION

The transmission and reception of a television signal is not very different from that of a radio signal. However, in television there are two signals to be taken care of, the sound signal and the picture signal. To transmit these two signals through the air, two rf carriers are needed, a picture carrier and a sound carrier. The sound signal in television is called the audio signal as it is in radio and the picture signal is called the video signal.

The sound signal is picked up by a microphone, fed to audio amplifiers and then used to modulate the sound carrier. However, in television, instead of varying the amplitude of the carrier, the frequency of the carrier is varied. This is called frequency modulation and is abbreviated FM. Some radio stations also use this type of modulation. They are called FM stations.

The picture is picked up by a camera that contains a set of lenses similar to the lenses used in a camera that takes photographs. The lenses project the picture on the face of a special tube called a camera pickup tube. This tube has a specially treated face plate on it and the light striking it produces a small voltage. The brighter the light, the more voltage produced. The pickup tube produces a video signal that varies in amplitude with the brightness of the different parts of the picture. The video signal is something like an audio signal; however, it is the electrical equivalent of the picture.

In a color television system, in addition to the signal that contains the brightness information, a color signal is developed, and this signal contains the color information. In other words, the video signal contains the information that tells how bright different parts of the picture are, and the color signal tells what color they are.

The video signal at the output of the pickup tube is fed to a stage called the video amplifier stage where the signal is amplified. In a transmitter, the video signal will be amplified by several video amplifiers. Similarly, in a color TV system, the color signal is amplified by color amplifiers. The color signal is then used to modulate an oscillator which is called a subcarrier oscillator, and this signal is combined with the video signal. The video signal and the color subcarrier signal are then used to amplitude-modulate an rf carrier. Amplitude modulation is used; this is the same type of modulation that is used in the standard radio broadcasting band.

Thus the TV transmitter, instead of transmitting only one rf signal, must actually transmit two rf signals, one to carry the sound signal and the other to carry the video signal along with the color signal if the broadcast is in color. The two signals from the transmitter are fed to a single antenna.

At the receiving installation, the two signals are picked up by one antenna, amplified by rf amplifiers and then separated from the rf carriers by separate detectors, one for the video and the other for the sound. In the case of a color television receiver, the video signal and the color subcarrier are separated from the video carrier and the color signal is then separated from the color subcarrier by a color detector.

The sound signal from the detector is amplified and fed to a speaker. The video signal is amplified and fed to the picture tube. In a black and white TV receiver the picture tube brightness is controlled by the video signal. In a color television receiver the brightness is controlled by the video signal which is mixed with the color signal to produce the original colors picked up by the camera.

This is only a brief run through of a

television transmitter and receiver. There are many details that have been simplified, many more that have been omitted, but you need not be concerned about them at this time. Keep in mind that the operation of the video portion of a TV transmitter is not very different from that of the audio portion of the transmitter. There are many differences in details, but the basic principles are the same.

SUMMARY

This brief description of a broadcasting system gives you a birdseye picture of what happens in a radio transmitter and a radio receiver. We do not expect you to remember the details at this time, but having a general idea of what takes place will help you with later lessons. Remember that an rf stage amplifies a radio frequency signal and that an audio stage amplifies an audio signal. Remember what an rf signal is, what an audio signal is and what a video signal is. You should also remember that the stage that separates the audio signal from the rf carrier and the stage that separates the video signal from the rf carrier are both called detector stages. You should remember the basic principles of the operation of a microphone and a speaker and also the schematic symbols for a microphone and an antenna.

SELF-TEST QUESTIONS

(v) How many kilohertz are there in a megahertz?

(w) Write 1900 kHz in megahertz.

(x) What is the name given to the electrical signal produced by sound striking a microphone?

(y) What is an audio stage?

(z) What is the name given to the stage in a transmitter that actually generates the radio frequency signal?

(aa) What is the name of the device used to feed an rf signal from the transmitter to the antenna?

(ab) What is the name given to the stage that separates the audio signal from the rf carrier?

(ac) What is the name of the small coil placed between the poles of the magnet in a speaker?

(ad) What are the names of the two signals that must be transmitted in a black and white television system?

(ae) What type of modulation is used in the sound section of a TV transmitter?

(af) What type of modulation is used in the video section of a TV transmitter?

Electronics in Industry

We have already mentioned that there are many uses for electronics in industry and that the number of applications is growing daily. Electronics is used in oil refineries to control the various steps in the refinement of crude oil. It is used in the livestock feed industry to control the mixing of grains and the preparation of feed for farm animals. It is used in the factories to control the operation of precision machines, to inspect the finished product coming off the assembly lines and to count the output of high-speed automatic machines. It is used by railroads to automatically guide loaded and/or empty cars in switching operations and to control the speed of the car so that it hits the cars already standing on the track at just the right speed to couple to the car without damaging the cars or their contents. We have all been thrilled in the past few years by the amazing feats performed by space ships sent to the moon to take television pictures of the moon, by the launching and orbiting of the ships and recovery of the astronauts. All these phenomenal feats have been possible due to many electronic devices at the control stations and aboard the space ships. In spite of all the advances we have made, the chances are that in the next ten years we will see even greater advances and even more opportunities in the field of electronics.

CHANGING AC TO DC

One of the important uses of electronics in industry is converting ac to dc. This can be accomplished by large electronic tubes designed for this type of service and by solid-state devices.

It is much more convenient to generate and transmit ac than it is dc. The reason for this is that ac can be transmitted at very high voltages. The higher the voltage is for a given amount of power to be transmitted, the lower the losses in the transmission lines will be. AC voltages can be conveniently increased or decreased by means of a transformer, whereas dc voltages cannot be changed from one value to another conveniently.

The Transformer. You have already briefly studied a simple transformer. A transformer consists of two coils wound on a common core. In the preceding lesson you learned that if a battery was connected to one winding and a switch inserted into the circuit and the switch opened and closed rapidly, the changing magnetic field set up in the one winding would induce a voltage in the second winding.

We call the winding to which the battery is connected the primary winding and we call the other winding the secondary winding. These names are easy to remember; remember that primary is first, and secondary is second.

If instead of a battery and switch, we connected ac voltage to the primary winding on the transformer, the ac voltage will cause an alternating current to flow in the primary winding. When the alternating current flows in one direction it will build up a magnetic field and the changing lines of force, as the field is built up, will cut the turns of the secondary winding and induce a voltage in these turns. As the ac current collapses and then begins to flow in the opposite direction, the magnetic field being produced will be continually changing. As the field builds up in the opposite direction, a voltage of the opposite polarity will be induced in the secondary winding.

The voltage that will be induced in the secondary winding will depend upon how many turns there are on the secondary winding. If the secondary winding has the same number of turns as the primary winding, the voltage induced in the secondary will be equal to the voltage applied to the primary. If the secondary winding has twice as many turns as the primary winding, the voltage induced in the secondary will be twice the voltage induced in the primary. A transformer of this type is called a step-up transformer because it steps the voltage up to a higher value. On the other hand, if the secondary winding has only half as many turns as the primary, the voltage induced in the secondary will be only half the voltage applied to the primary. This type of voltage is called a step-down transformer because it steps down the voltage.

Thus by means of a step-up transformer an ac voltage generated by a generator can be stepped up to a very high value. It can then be transmitted to a distant point by means of high-voltage transmission lines and at that point stepped down by means of a step-down transformer. This is why it is more convenient to transmit alternating current than direct current.

Alternating current is changed to direct current by means of rectifiers. A rectifier is a device that will let current flow through it in one direction, but will not let it flow through it in the opposite direction. You will learn about tube rectifiers now and about other types later.

Half-Wave Rectifiers. A half-wave rectifier is a device that will allow current to flow during only one half of each cycle. Remember that the ac cycle we looked at before in Fig. 13 had a positive half and a negative half. A half-wave rectifier can be connected to allow current to flow either during the positive half or during the negative half of the cycle, but it will not let current flow during both halves of the cycle.

A schematic diagram of a half-wave rectifier circuit is shown in Fig. 24. You are already familiar with the schematic symbols used on this diagram. T_1 and T_2 are iron-core transformers, and V_1 is a tube with a filament and a plate. Notice that the tube is drawn upside down. You will find them drawn in any position on schematic diagrams, but the pointed symbol is always the filament and the straight line is the plate. On the schematic diagrams the dots where several connecting lines meet indicate a connection. The crossovers without a dot indicate that there is no connection.

Now let us study Fig. 24. The ac power from the power line is fed to the primary

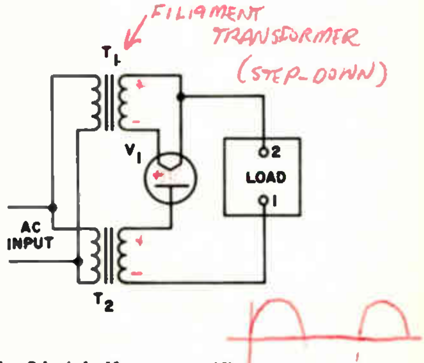


Fig. 24. A half-wave rectifier circuit.

winding of the transformers marked T_1 and T_2. T_1 is a step-down transformer. The winding on this transformer provides the voltage necessary to heat the filament of the diode tube. This transformer is often called a filament transformer because it supplies the power required to heat the tube and serves no other useful purpose in the circuit.

Transformer T_2 may be either a step-up or step-down transformer depending upon the dc voltage required by the load. If the dc voltage needed is higher than the power line voltage, a step-up transformer is used, whereas if it is lower, a step-down transformer is used. The block marked "load" on the diagram represents whatever is going to use the dc power produced. This might be a number of storage batteries we are charging, or it could be a bath which is being used to refine copper or aluminum in a refinery. You will see the word load used frequently in this way.

Now let us see how the half-wave rectifier works. Refer to Fig. 25 as you read the explanation. We have simplified the figure by leaving out the filament transformer T_1 and the primary winding of T_2. The filament transformer T_1 heats the tube filament, but does not enter into the operation of the rectifier in any other way.

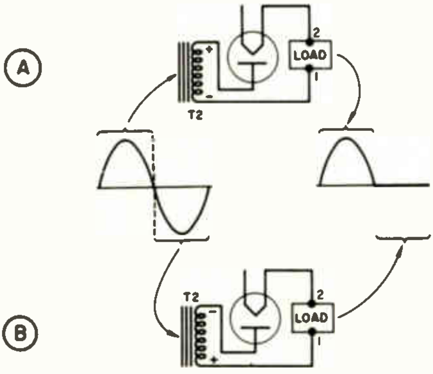


Fig. 25. How a half-wave rectifier works.

Looking at Fig. 25A we see the first half cycle which is the positive half cycle. At the left of the drawing we see the ac voltage across the secondary of T_2. In the center we see the polarity of the voltage across the secondary of T_2 and at the right we see the voltage that will appear across the load. The voltage will cause a current flow through the load. During this half cycle, the end of the secondary winding of T_2 which is connected to the plate of the diode tube is positive and the other end is negative. When this happens, current will flow from the lower end of the transformer winding to terminal 1 of the load, through the load to terminal 2 and to the filament of the tube. You know that the red-hot filament will emit or give off electrons. These electrons will be attracted to the plate of the tube by the positive voltage on the plate. Therefore, the electrons will flow from the filament to the plate of the tube to the positive end of the transformer. Since this is a complete circuit, current can flow.

However, when the polarity of the voltage across the secondary of T_2 reverses, we will have the negative half cycle shown in Fig. 25B. The polarity of the secondary of T_2 is shown. Notice that the end of the secondary winding connected to the plate of the tube will be negative and the other end will be positive. Now let us see how current will have to flow during this part of the cycle.

You will remember that current flows from the negative terminal of the voltage source through the external circuit and back to the positive terminal of the source. This means the electrons will have to flow from the negative end of the secondary winding of the transformer to the plate of the tube. They could do this, but then they would have to flow from the plate of the tube to the filament. However, there is no way the plate can give off electrons. Furthermore, electrons will not flow from the filament of the tube to the plate because they will be repelled by the negative voltage on the plate. The plate will be negative because the side of the transformer it is connected to is negative during this half cycle. Since electrons cannot get across the tube there is no complete circuit and, therefore, there will be no current in the circuit.

The current in a half-wave rectifier of this type will look like the drawing in Fig. 25. Notice that during the first half of the cycle when the plate is positive there will be current through the circuit. During the next half cycle when the plate is negative there is no current. This chain of events will continue so that during the third half cycle when the plate becomes positive again, current will flow and then during the fourth half cycle again there will be no current. The current will flow in pulses, with one pulse for each cycle. Again, this type of dc is called a pulsating dc and the rectifier is called a half-wave rectifier because it rectifies only one half of each cycle.

In a practical circuit the need for two transformers can be avoided by putting two secondary windings on one transformer. One winding as a step-down winding provides the voltage needed to operate the filament of the rectifier tube. The other winding may be either a step-up or a step-down winding depending upon the dc voltage required by the load.

SILICON RECTIFIERS

In many applications silicon rectifiers have replaced diode tubes. The advantage of a silicon rectifier is that it does not have a filament and hence does not use any power to heat the filament such as a tube does. In addition, silicon rectifiers are quite small and can pass rather large currents for their size. They have an additional advantage in that there is very little voltage lost across the rectifier, whereas in a tube there will be some voltage lost across the tube. A silicon rectifier is made of two different types of silicon placed together to form a junction. This junction will permit current to cross it in one direction, but will not permit it to cross in the other. In the forward direction there is practically no resistance in the junction and therefore the current flows freely in that direction. In the reverse direction, the junction offers such a very high resistance that practically no current crosses it.

A schematic diagram of a half-wave rectifier using a silicon rectifier is shown in Fig. 26. The arrows indicate the

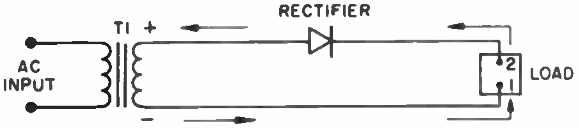


Fig. 26. A half-wave rectifier using a silicon rectifier.

direction in which current will flow during the half cycle the rectifier passes current.

Notice that the arrows indicating the direction of current flow point in the opposite direction to the arrow used as part of the symbol in the silicon rectifier. The reason for this is that the symbol dates back to the early days of electricity when engineers and scientists thought that current flowed from the positive terminal of a battery or generator through the load and back to the negative terminal. Hence the symbol was drawn with the arrow indicating this direction of current. Now we know that current flows in the opposite direction, but the symbol has been carried over to indicate a solid-state rectifier such as a silicon rectifier and the arrow points in the wrong direction. Remember this symbol, it is used to represent all types of solid-state devices that will permit current flow in only one direction. It is used to represent detectors made out of germanium which can be used in radio and television receivers; it is used to represent selenium rectifiers which are another type of solid-state rectifier; and it is used to represent copper-oxide rectifiers which are used in meters. You will learn more about these devices later. They are often called diodes because there are two types of material used in them.

SUMMARY

At this time you need not remember all the details of how a rectifier operates. However, you should remember that a rectifier is a device that will permit current to flow through it in only one direction. By using a rectifier, alternating current can be changed to pulsating direct current. Remember that a half-wave rectifier rectifies only half of each cycle so that you'll get a pulse during one half cycle and no current during the next half cycle.

SELF-TEST QUESTIONS

(ag) What is the name given to a transformer where the secondary voltage is higher than the primary voltage?

(ah) If a transformer has fewer turns on the secondary winding than it has on the primary winding, will the secondary voltage be equal to, greater than or less than the primary voltage? What is the name given to this kind of transformer?

(ai) In a half-wave rectifier circuit, in which direction will current flow through a diode tube?

(aj) What must the polarity of the voltage on the plate of a diode rectifier tube be in order for current to flow in a half-wave rectifier circuit?

(ak) Draw the schematic symbol for a silicon rectifier and by means of an arrow above it indicate in which direction the current will flow through the rectifier.

(al) When two connecting lines cross and there is a dot placed on the junction, what does this indicate?

Electronics for Computers

Almost all of the electronic circuits used in communications equipment, industrial applications and in computers operate from direct current. While this dc could be obtained from a set of batteries, most often it is obtained from a power supply that consists of a power transformer and rectifier similar to that discussed in the previous section. The transformer takes the ac line voltage and steps it up or down to the required voltage level. The rectifier then converts this ac into a pulsating dc. This pulsating dc is then fed through a filter circuit to smooth it into a clean pure dc signal very similar to that obtained from a battery. The resulting dc voltage is then used to power the various electronic circuits used in communications, industrial and computer equipment.

The sine wave is the basic electrical signal used in communications and industrial electronic equipment. In communications equipment, oscillator circuits are used to generate a sine wave signal and produce a carrier signal that is radiated by the transmitter and detected by the receiver. In computer circuits, however, the sine wave is not the basic electrical signal. Computers use another class of signals known as pulse signals. Let's take a look at some of these interesting signals and see how they are produced and used in computers.

PULSE SIGNALS

A pulse signal is an electrical voltage or current that switches rapidly from one voltage level to another and back again. A simple pulse signal is shown in Fig. 27. Notice that this signal switches rapidly from a zero volt level to a 10 volt level and then back again to zero, repeating itself periodically. The resulting wave shape of this signal is approximately square and, therefore, this pulse signal is often referred to as a square wave or more generally as a rectangular wave. This signal is basically a pulsating dc signal similar to the output of the half-wave rectifier you studied in the previous section. The difference between this signal and the rectifier output is the wave shape.

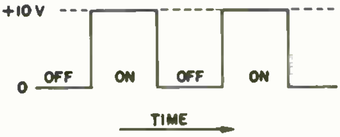


Fig. 27. A simple pulse signal.

A pulse signal like this is relatively easy to generate. In fact, we could generate it very simply with the battery and switch circuit shown in Fig. 28. When the switch is open, or off, no voltage appears between points A and B. However, when we close the switch or turn on the circuit, the battery voltage appears between points A and B. If we turn the switch off

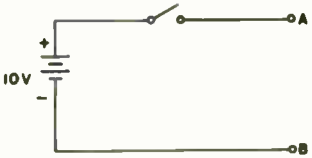


Fig. 28. One means of generating a square wave.

and on at a rapid rate, it will produce a square wave similar to that shown in Fig. 27.

While pulse signals are sometimes produced with a circuit as simple as that shown in Fig. 28, they are usually produced by electronic circuits known as multivibrators. A multivibrator generates a very fast high frequency square wave whose frequency, amplitude and pulse width can be varied over wide ranges.

Any pulse signal is usually specified by these three characteristics: frequency, amplitude and pulse width. Frequency is the rate at which the pulses occur. The amplitude of the pulse is the amount of voltage or current that it represents when it is "on". Pulse width designates the amount of time that the pulse is "on".

There are a wide variety of different pulse signals that you may encounter in computers and in other electronic equipment. The signal in Fig. 29A is a rectangular wave that switches from 0 to +5 volts. This signal is similar to that shown in Fig. 27 with the exception that the amplitude of the voltage is less and the off and on times are unequal. It is quite common to have unequal off and on periods in a pulse signal. Here we show the on period being longer than the off period. However, just the opposite could be true in another waveform.

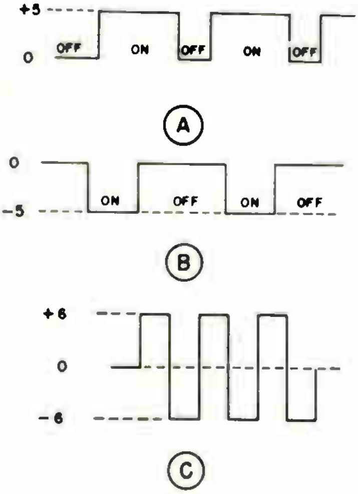


Fig. 29. Some different types of rectangular pulses. (A) unequal on-off times; (B) negative going pulses; (C) an ac square wave.

Fig. 29B shows another rectangular waveform where the voltage switches from 0 volts to –5 volts. It is easy to generate either positive or negative voltage signals with pulse circuits.

In Fig. 29C we show yet another type of pulse circuit that switches between two voltage levels, +6 volts and –6 volts. This type of pulse signal is really an ac signal since it produces an alternating current. When the pulse is positive, the voltage will cause electrons through a circuit to flow in one direction. When the voltage is negative, electrons will flow through the circuit in the opposite direction.

The pulse waveforms we have shown here are typical of what you might encounter in computer equipment but other variations are possible. Pulse signals like these are also used in television, telemetry and communications equipment. Just keep in mind the basic fact that a pulse signal usually switches rapidly between two voltage or current levels rather than varying smoothly and continuously like a sine wave does.

LOGIC CIRCUITS

There is a special class of electronic circuits known as logic circuits that are used to process or manipulate the pulse signals you have just studied. Such cir-

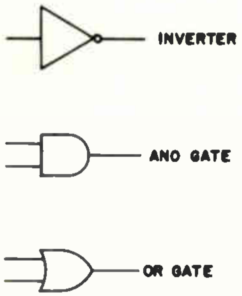


Fig. 30. The three basic digital logic circuits.

cuits are also referred to as digital circuits. The three basic logic circuits are the inverter, the AND gate, and the OR gate. The symbols representing these three basic digital circuits are shown in Fig. 30. Let's see how these circuits work. All of these circuits operate on pulse signals similar to those shown in Fig. 27 and 29.

An inverter circuit does exactly what it says, it inverts a pulse signal so that the inputs and outputs are going in opposite directions. We say that the signals are complements of one another. For example, if a pulse switching from +5 volts to 0 volts is applied to the input of an inverter as shown in Fig. 31A, the resulting output will be a signal that switches from 0 to +5 volts at the output. A positive-going pulse at the input to an inverter produces the negative-going pulse on the output.

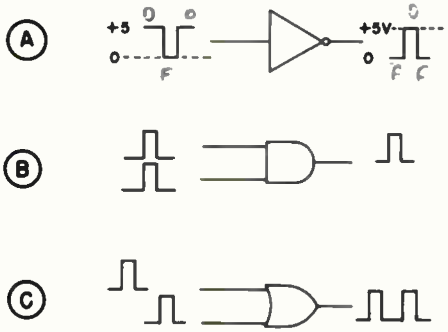


Fig. 31. (A) inverter operation; (B) AND gate operation; (C) OR gate operation.

An AND gate is a logic circuit that produces an output pulse if two or more pulses are applied to its inputs simultaneously. See Fig. 31B. An AND gate can have two or more inputs and a single output. The gate does not produce an output signal unless input signals are applied to all of its inputs simultaneously. If an input signal occurs on only one of the input lines, no output pulse will be produced. The AND gate is commonly referred to as a coincidence gate since it produces an output only when the two inputs are coincident in time.

Fig. 31C shows how the OR gate works. The OR gate also has one output and can have two or more inputs. It produces an output any time a pulse occurs on any of its inputs. In Fig. 31C we show two pulses occurring at different times at the two inputs. An output pulse is produced for each of the input pulses.

Any digital logic function can be performed by just these simple circuits. More complex operations than those described here are performed by combining these three circuits. Any digital computer is made up of nothing but a large quantity of these three basic types of circuits. A digital computer or other large digital system may be very complex. However, if you understand the operation of the three simple circuits discussed here, you can easily learn how the more complex systems work. This is true, of course, of any piece of electronic equipment. If you learn how the basic simple circuits such as oscillators, amplifiers and power supplies work, you will then be able to understand more complex pieces of equipment. In your NRI lessons to come, you will study these important fundamental circuits to prepare you for more complex equipment.

Now answer the self-test questions on this section and then do the lesson questions. Remember that if you have difficulty with the self-test questions it is an indication you need to go over the section again. Do not hesitate to spend any time you need to review. Learning the basic fundamentals you are studying now is the most important part of your course. If you understand these fundamentals, you will be able to build on them in later lessons and you will find that as you go on your course becomes easier and easier. On the other hand, if you do not master the fundamentals covered in the early lessons you will find it difficult to grasp some of the ideas presented in later lessons.

SELF-TEST QUESTIONS

(am) What is the main difference between a pulse signal and a sine wave signal?

(an) Name three characteristics by which a rectangular pulse signal is usually specified.

(ao) Which type of logic circuit produces an output pulse if input pulses occur on either of its two inputs?

(ap) True or False? A pulse signal can be either ac or pulsating dc.

Answers to Self-Test Questions

(a) 1-1/2 volts.

(b) 22-1/2 volts. Each cell has a voltage of 1-1/2 volts and since there are fifteen cells, the voltage will be 1-1/2 × 15 = 22-1/2 volts.

(c) 1-1/2 volts. When cells are connected in parallel the voltage of all the cells must be equal and the total voltage of the cell will be equal to the voltage of one cell. Connecting cells in parallel does not increase the voltage -- it increases the current capabilities of the battery.

(d) +4-1/2 volts. The battery will be marked essentially the same as the battery in Fig. 4. Since one terminal is marked with a – sign, we consider this terminal as the reference point. The center tap has three cells between it and the reference point and therefore the voltage will be 4-1/2 volts. It will be marked + to indicate that this terminal is positive with respect to the negative terminal.

(e) A longer shelf life and a higher current capacity.

(f) 1.35 volts or 1.4 volts, depending upon the materials used in the mercury cell.

(g) 1.5 volts. The output voltage of a manganese cell is approximately the same as the output voltage of a dry cell.

(h) The manganese cell has not replaced the dry cell because it is more expensive than the dry cell, so in many cases the economy of the dry cell overrules the advantages of the manganese cell.

(i) The lead-acid cell and the nickel-cadmium cell.

(j) The nickel-cadmium cell provides longer life and more maintenance-free performance than the lead-acid cell because it can be sealed and hence water does not escape from it when it is charged.

(k) Direct current and alternating current.

(l) DC voltage.

(m) AC voltage.

(n) The voltage wave supplied by the power company is called a sine wave.

(o) The waveform shown in Fig. 13B represents one cycle. In a cycle of alternating current, the voltage between the two terminals of the generator starts at zero and then builds up to a maximum value with one polarity and then drops back to zero; it then builds up to a maximum value with the other polarity and then drops back to zero. During the next cycle it will simply repeat the first cycle.

(p) 60 cycles per second means that we have 60 complete cycles in a second. This means that the voltage starts at zero, builds up to a maximum with one polarity, drops back to zero, builds up to a maximum value at the opposite polarity and drops back to zero a total of sixty times in a second.

(q) A commutator.

(r) A simple dc generator such as shown in Fig. 14 would produce a pulsating dc such as shown by the waveform in Fig. 16. A pulsating dc of this type is normally not desired and the excessive pulsating can be eliminated by means of an armature such as shown in Fig. 17. In this armature a number of series-connected coils are used and a more even dc is produced.

(s) When we say that the ac current is 1 amp we mean that the ac current is the equivalent of 1 amp of direct current. In other words, if an ac current of 1 amp is flowing through the coils of a heater, it will produce the same amount of heat as a dc current of 1 amp flowing through the same coils would produce.

(t) When we give an ac voltage and do not specifically mention that it is the peak value, we always assume that the value is meant to be the effective or rms value of the voltage. If we want to give the peak value of an ac voltage, we should specifically state that it is the peak value, otherwise it would be assumed to be the effective or rms value.

(u) 280 volts. The peak value of an ac voltage is 1.4 times the rms value. Thus if the rms value is 200 volts, the peak value will be: 200 X 1.4 = 280 volts.

(v) There are 1,000 kilohertz in one megahertz.

(w) 1900 kHz = 1.9 MHz.

(x) An audio signal.

(y) An audio stage is a stage designed to amplify an audio signal. The stage may consist of a tube and a number of components or it may consist of a transistor and a number of components.

(z) The oscillator stage.

(aa) The transmission line.

(ab) A detector stage or a demodulator stage. Both names are used.

(ac) A voice coil.

(ad) The audio signal which carries the sound information and the video signal which carries the picture information.

(ae) Frequency modulation (FM) is used in the sound section of a TV transmitter.

(af) Amplitude modulation (AM) is used in the video section of a TV transmitter.

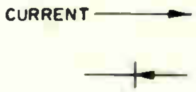
(ag) A step-up transformer.

(ah) Less than; a step-down transformer.

(ai) Current flows from the filament or cathode to the plate.

(aj) The plate must be positive.

(ak)



(al) It indicates a connection between the two circuits.

(am) A pulse signal switches abruptly from one voltage level to another while a sine wave varies smoothly or continuously between its two peak levels.

(an) Frequency, amplitude and pulse width.

(ao) An OR gate.

(ap) True.

YOU'VE GOT COURAGE

An eight year old boy was discussing arithmetic with a friend. Said Johnny: "Teacher's gonna start us on subtraction tomorrow; wish I could stay home." But Harry laughed outright at Johnny's fears, and said; "Aw, I've had that and it's easy once you get started; what I'm worrying about is multiplication!"

It is natural even for grown men to feel like these boys – to fear most the things about which they know the least.

Did you know that some of the world's best speakers are always afraid when they get up to make a speech before a strange audience? Their courage gets them started, and in no time at all their fear changes to a confident enthusiasm which makes their talk a big success.

You've got courage! Use your courage to overcome normal fears, to carry you into each new subject and carry you over each difficulty. In no time at all, you will be looking forward to new subjects with intense interest – you will be eager to tackle new problems. Remember that each conquered difficulty brings you one step closer to your goal of SUCCESS IN ELECTRONICS!

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CURRENT, VOLTAGE, AND RESISTANCE

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CURRENT, VOLTAGE AND RESISTANCE

B103

STUDY SCHEDULE

By dividing your study into the steps given below, you can get the most out of this part of your NRI Course in the shortest possible time. Check off each step when you finish it.

☐ 7. Answer the Lesson Questions.

☐ 8. Start Studying the Next Lesson.

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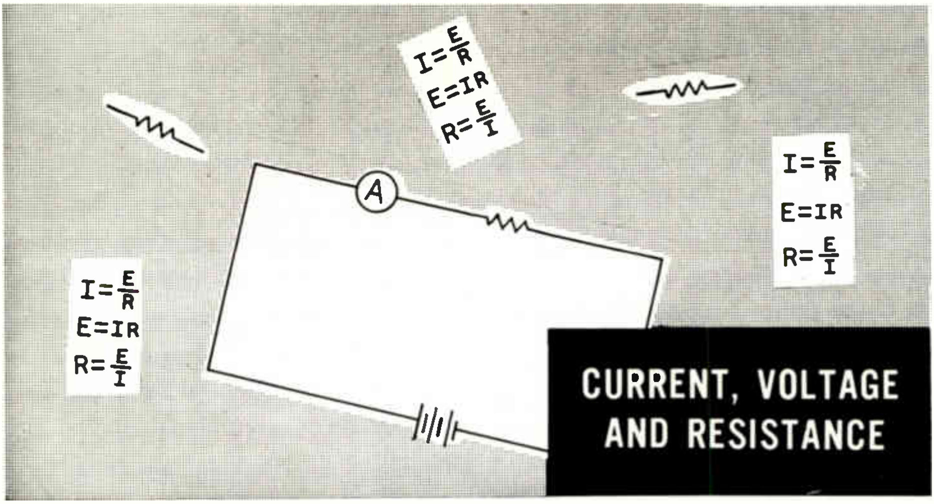


CURRENT, VOLTAGE AND RESISTANCE

Have you ever looked into the back of a color television receiver? If you have, you probably wondered how it would be possible to identify the parts in the set and to trace out the circuits. You may have wondered how an experienced technician can find a defective part among the maze of parts and circuits in the receiver. The technique that he uses is the same as the technique that you are going to learn now. Most of the circuits in a color television receiver or in any other piece of electronic equipment are basically rather simple circuits. The difficulty comes from the fact that so many of them are used together. However, once you learn how to trace simple circuits and understand what is happening in the circuit you will find that you will be able to apply that knowledge to more complex circuits, and also to larger groups of simple circuits when they are used together.

Your first two lessons introduced you to a number of important things in the field of electronics. You learned the important laws of electric and magnetic charges: like charges repel, unlike charges attract. In magnets like fields repel and unlike fields attract. You also learned that an electric current was a movement of electrons. You already know that an electron has a negative charge and that it will be attracted by a positive charge and repel other negative charges.

You learned about direct and alternating currents and studied batteries and generators. You also took a quick look at a broadcast system and learned what is meant by an audio signal and a radio frequency signal.

We will go into more detail later on the various things covered in your first two lessons. These lessons were primarily introductory lessons to get you started. In this lesson we will start going into considerable detail. You will learn that the units of electrical measurement - the volt, the ampere, and the ohm - are in some cases too small and in other cases too large. You'll learn how to convert them into practical sizes when necessary.

You will study simple circuits and learn how voltage, current and resistance are related in these circuits. You will study Ohm's Law; this is a very simple law, but it is probably the most important rule or law in electronics. You will use Ohm's Law over and over again as long as you are in the electronics field.

As you study this lesson, keep in mind that it is perhaps the most important lesson in your entire course. You must understand basic simple circuits thoroughly. If there is anything you do not understand, be sure to go over that section of the lesson several times. If you can't work it out for yourself be sure to write to NRI and ask for help. Our instructors will be glad to help you; they all agree that this is a very important lesson and will do everything they can to be sure that you understand the entire lesson.

Pay particular attention to the self-test questions. These questions will tell you whether or not you have learned all you should have about each section of the lesson as you go along. If you find there is a self-test question you cannot answer, this means you need to restudy that section of the lesson. Don't be afraid to go back and spend whatever extra time may be necessary. A little extra time on this lesson will pay great dividends in later lessons not only in helping you understand these lessons better, but it will also make it easier for you and save time in the long run.

Now let us go ahead and learn more about current, voltage and resistance. We will study current first, then voltage, and finally resistance. In each case, we will review the important points that you already know, and then go ahead and expand that knowledge.

Current

You have already learned that an electron is part of an atom. An electron has a negative electrical charge. All electrons have exactly the same negative electric charge. Electrons repel each other because like charges repel. Electrons are repelled by all negative charges and attracted by all positive charges.

An electric current is the movement of electrons in the circuit. There are two kinds of electric current, direct current and alternating current. Let us discuss direct current first.

DIRECT CURRENT

When a battery is connected to an electric circuit, electrons are repelled from the negative terminal of the battery and attracted by the positive terminal of the battery. Electrons move in one direction through the circuit. This type of current flow is called direct current. We usually refer to it simply as dc.

In a simple circuit such as shown in Fig. 1, it is important for you to remember that the current flow is the same in all parts of the circuit at all times. The number of electrons leaving the negative terminal of the battery is exactly the same as the number of electrons passing point A on the wire connecting the battery to the lamp. The number of electrons flowing through the lamp is the same as the number of electrons passing point B on the other wire, and the same number of electrons are moving into the positive terminal of the battery.

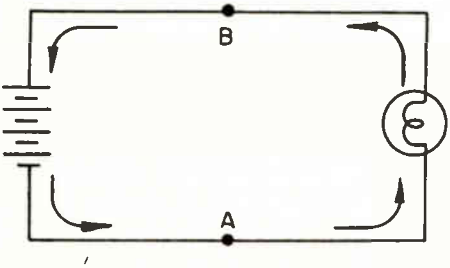


Fig. 1. A simple dc circuit.

Another important point that you must remember about an electric current is that the instant the circuit is closed, the electrons start moving in all parts of the circuit. One electron does NOT leave the negative terminal of the battery, hit another, and so forth, and thus start movement in the circuit after a certain period of time; each electron starts movement immediately the moment the circuit is completed.

The unit of current flow is the ampere which we usually abbreviate amp. A current of 1 ampere represents a certain number of electrons moving past a point in the circuit in a second. If twice as many electrons are moving past that point in the circuit, the current flow is 2 amperes, and if ten times the number of electrons are moving past the point in the circuit, the current flow is 10 amperes.

Direct current is widely used in electronic equipment. Current will flow through a vacuum tube or a transistor in only one direction and therefore the current used to operate these devices is direct current. There are other applications of direct current in industry. Direct current is used in purifying metals, in plating operations and in running some motors that require precise controls. Direct current motors can be more closely controlled than alternating current motors.

ALTERNATING CURRENT

The electric current supplied to homes for lighting, for cooking and operation of small appliances is alternating current. An alternating current flows first in one direction and then in the other direction. The current starts at zero amplitude and builds up to a maximum value which we call the peak value, then drops back to zero, then builds up to a peak value flowing in the opposite direction, and then drops to zero again. This action of flowing first in one direction and dropping back to zero value, then building up to a maximum value in the opposite direction and then once again dropping back to zero is called a cycle. The current supplied by most power companies is 60-cycle current. This means that it goes through 60 cycles per second.

Alternating current is also measured in amperes. However, since the number of electrons flowing past a point in the circuit is continually changing when we have alternating current, we use a somewhat different method of expressing the value of the current. The alternating current is compared to direct current. If the alternating current flowing through a heat-producing device produces the same amount of heat as a direct current of 1 ampere produces, we say that the ac current is 1 ampere. We call this the effective value or the rms value.

The change in amplitude of an alternating current follows a pattern or waveshape which is known as a sine wave. A typical sine wave showing one complete cycle is shown in Fig. 2. In this figure the rms value of the alternating current is 1 amp. As you can see, for part of the cycle the actual current flowing will be less than 1 amp and during part of the cycle it will be greater than 1 amp. The actual peak or highest value that the current reaches is 1.4 × the rms value. In the example shown, where the rms value is 1 amp, the peak value will be 1.4 amps.

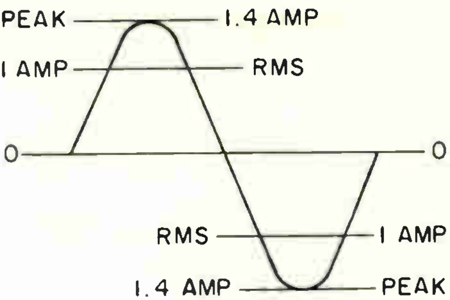


Fig. 2. A sine wave showing rms and peak values.

In the first half cycle, we have drawn the waveshape above the horizontal line representing zero current. This half of the cycle is referred to as the positive half cycle. The other half cycle is referred to as the negative half cycle. Notice, the negative half is exactly the same as the positive half. The current reaches the same rms and the same peak values. We simply call one a positive half cycle and the other a negative half cycle to indicate that the current is flowing in opposite directions during the two half cycles.

To convert rms values of current to peak values you multiply the rms value by 1.4. If you have the peak value of the current and want to convert it to the rms value, you simply divide by 1.4.

THE MILLIAMPERE

While the unit of current measurement is the ampere, in electronics this unit is often so large that it is cumbersome. For example, in an audio amplifier stage using either a tube or a transistor, the current flow may be only a few thousandths of an ampere. In a case where the current flow was three thousandths of an ampere we could write this as 3/1000 or we could write this value as a decimal, in which case it would be .003.

However, rather than do this it is much more convenient to express the current flow in milliamperes. A milliampere is one thousandth of an ampere. Thus a current flow of three thousandths of an ampere will be 3 milliamperes.

There are one thousand milliamperes in an ampere. Therefore to convert amperes to milliamperes you simply multiply by one thousand. You do this by moving the decimal point three places to the right. For example, suppose you have a current of 5 amperes. We would normally simply write this as 5 amps. However, we can also write it as 5. amps. Now to move the decimal point three places to the right we simply add three zeros to the right of the decimal point, and then move the decimal point to the right of the three zeros. Thus 5.000 amps becomes 5,000. milliamps.

We seldom use milliamperes to express currents that are over 1 ampere, but when the current is some fraction of an ampere the milliampere becomes particularly useful. For example, suppose the current flow in a circuit is .05 amperes. To change this to milliamperes we move the decimal point three places to the right. To do this, write .05 amps as .050 amps and then move the decimal point three places to the right. Thus .05 amps = .050 amps = 50 milliamperes.

If you have a current in milliamperes and want to convert it to amperes you move the decimal point three places to the left, adding zeros as necessary. For example, to convert 47 milliamperes to amps we first write 47 milliamperes as 47. milliamperes. Now we move the decimal point three places to the left by moving it past the 7 and past the 4. Now we add a 0 so we can move the decimal point three places and get .047 amps. Another example, suppose the current is 7 milliamperes and we want to convert this to amperes. We write 7 milliamperes as 7. milliamperes. Next, we move the decimal point three places to the left; we move it past the 7 and then add two zeros to the left of the 7 and get .007 amps.

You will deal with milliamperes a great deal in electronics, and often you will have to convert them to amperes. Remember the rules for converting back and forth. To convert milliamperes to amperes you move the decimal point three places to the left. To convert amperes to milliamperes you move the decimal point three places to the right. In effect, when you convert from milliamperes to amperes by moving the decimal point three places to the left, you are dividing by 1000. When you convert amperes to milliamperes by moving the decimal point three places to the right, you are multiplying by 1000.

Since we use milliamperes so often in electronics it is convenient to have an abbreviation for this rather long word. We often abbreviate milliampere milliamp and to make it plural we simply add an s. An even more convenient abbreviation is ma. Thus 27 milliamperes can be abbreviated 27 milliamps or 27 ma.

You might think that converting from amperes to milliamperes and from milliamperes back to amperes is difficult and something that you are not used to doing. This is not true. Whether you realize it or not you are doing conversions of this type all the time. For example, suppose somebody gave you four hundred cents. It is not too likely that you would say that you had four hundred cents. Chances are that you would convert cents to dollars by moving the decimal point two places to the left and say you had $4.00. However, if you did have $4.00 and wanted to change it to cents you would move the decimal point two places to the right and know that you should have four hundred cents. The conversion back and forth between amps and milliamps is exactly the same except that we have one additional place. To convert from the larger unit, dollars in one case and amperes in the other, to the smaller unit, cents in one case and milliamperes in the other, we move the decimal point to the right. To convert from the smaller unit (cents in the one case and milliamperes in the other) to the larger unit (dollars in the one case and amps in the other case) we move the decimal point to the left. Remember the dollars and cents conversion and remember that you have one extra place and you will have no difficulty changing back and forth between amps and milliamps; it is that easy.

THE MICROAMPERE

In some circuits, even the milliampere is too large a unit to conveniently express current flow. Thus we have an even smaller unit, the microampere, which we abbreviate microamp. The microamp is one millionth of an ampere. It is one thousandth of a milliamp.

To convert amps to microamps you move the decimal point six places to the right. Remember it is the same as converting amps to milliamps except that you move the decimal point six places instead of three places. To convert microamps to amps you move the decimal point six places to the left. This is the same as converting milliamps to amps, or cents to dollars except that you move the decimal point six places to the left.

Even the abbreviation microamp is somewhat long and inconvenient, and since we have already used the letter ma for milliamps, we use the Greek μ which looks something like our u to abbreviate microamps. We write it μa.

Sometimes you will want to convert microamperes to milliamperes and vice versa. To do this, you move the decimal point three places. To go from the larger unit, milliamperes, to the smaller unit, microamperes, move the decimal point to the right, and to go from the smaller unit to the larger unit move it to the left.

In Fig. 3 we have shown a number of examples of conversions from one unit to another. Before going ahead study this figure and the conversions and then try to do them yourself. This is the best way to learn how to convert from one unit to another. Once you learn how to do this you

LARGE TO SMALL	SMALL TO LARGE
Dollars To Cents $1 = 100 cents We moved the decimal point 2 places to the right. $1 = $1.00 $1.00 = 100 cents	**Cents To Dollars** 1000 cents = $10.00 = $10. We moved the decimal point 2 places to the left. 1000. ¢ = $10.00
Amps To Milliamps 1 amp = 1000 milliamps We moved the decimal point 3 places to the right. 1 amp = 1.000 amp 1.000 amp = 1000 milliamps	**Milliamps To Amps** 10 milliamp = .010 amp We moved the decimal point 3 places to the left. 10. milliamp = .010 amp = .01 amp
Amps To Microamps 1 amp = 1000000 µamp We moved the decimal point 6 places to the right. 1 amp = 1.000000 amp 1.000000 amp = 1000000 µamp	**Microamps To Amps** 100000 µamps = .100000 amp We moved the decimal point 6 places to the left. 100000. µamp = .100000 amp = .1 amp

Fig. 3. Examples of conversion from one unit to another.

will find it is really quite simple and in a very short while you will find that you are converting from one unit to another mentally just as easily as you convert dollars and cents.

SUMMARY

In this section of the lesson you have reviewed many of the things you learned earlier about current flow. The important thing to remember about current flow is that it is a movement of electrons, and that in a series circuit the current flowing is the same at all parts of the circuit. Also remember that once the circuit is completed, current starts to flow in all parts of the circuit at the same instant.

You learned that to convert from rms values to peak values of ac current you multiply the rms value by 1.4 and to convert from peak values to rms values you divide by 1.4. The milliampere is one thousandth of an ampere. The microampere is one millionth of an ampere. To convert from the larger units to the smaller units you move the decimal point to the right and to convert from the smaller units to the larger units you move it to the left. In converting amperes to milliamperes and vice versa you move the decimal point three places, and in converting amperes and microamperes you move it six places. In converting microamperes and milliamperes you move the decimal point three places. These conversions are the same as converting dollars and cents and it is something that you will learn to do almost automatically.

Fig. 3 shows a number of examples of how to convert the different units. Be sure to study this figure carefully and then do the self-test questions. When you are doing these questions, if there is a conversion you do not know how to do, look at Fig. 3 and try to work it out yourself. If you can't, go to the back of the book and see how the conversion is made. Just look at the one you can't do and then go back to the self-test questions. There are several examples of each type of conversion. They are put in deliberately so that if you have trouble with the first one you can look at Fig. 3 to get help. Then look at the answer for additional help if necessary, and have another crack at doing it yourself. Changing back and forth becomes almost automatic - you simply move the decimal point the correct number of places.

SELF-TEST QUESTIONS

(a) If the current flowing past a point in the circuit is 1 ampere and it is increased so that four times the number of electrons pass the point in a second, what will the new current flow be?
(b) If the rms value of current is 3 amps, what will the peak value be?
(c) Change 7 amps rms to its peak value.
(d) If the peak value of current in a circuit is 7 amps, what is the rms value?
(e) In a circuit, the peak value of current is 21 amps; find the rms value.
(f) Convert $6.00 to cents.
(g) Convert 350 cents to dollars.
(h) Change 2 amps to milliamps.
(i) Convert 6 amps to milliamps.
(j) Convert 3.5 amps to milliamps.
(k) Convert .42 amps to milliamps.
(l) Convert .037 amps to milliamps.
(m) Convert .002 amps to milliamps.
(n) Convert 46 ma to amps.
(o) Convert 822 ma to amps.
(p) Convert 1327 ma to amps.
(q) Convert 2 amps to μa.
(r) Convert .0017 amps to μa.
(s) Convert 20 μa to amps.
(t) Convert 147 μa to amps.
(u) Convert .26 ma to μa.
(v) Convert .031 ma to μa.
(w) Convert 6100 μa to ma.
(x) Convert 927 μa to ma.
(y) Convert 327,000 μa to ma, and then to amps.

.026 600

Voltage

You have already learned that voltage is the electrical pressure or force that can set electrons into motion. You know that two voltage sources are the battery and the generator. You also know that the unit in which voltage is measured is the volt.

Now let us review some of the important things you learned about voltage, and then expand that knowledge.

DC VOLTAGE

You know that dc is the abbreviation for direct current. A dc voltage is a voltage that will cause a direct current to flow. We refer to this voltage as dc voltage, not direct current voltage.

A battery is an excellent source of a dc voltage. The battery will supply a potential that will cause a constant current to flow in one direction. A dc voltage will cause a current flow from the negative terminal of the voltage source, through the circuit to the positive terminal of the source.

In the early days of radio, radios were built on a metal chassis and one side of the voltage source used to operate the radio was connected to this chassis. The chassis in turn was usually connected to a ground, such as a water pipe or a metal pipe driven into the ground. As a result, the connection to the chassis became known as the ground connection.

Today, you should not connect the chassis of a radio or television receiver to a ground connection because you might place a short across the power line if you do this. However, if the chassis is still connected to one side of the voltage source operating the radio or television set we still refer to it as a ground connection. Sometimes instead of using the chassis as a common connection for the various circuits in the receiver, we run a series of connections from one common point in the receiver to another and back to one side of the voltage source. We call this type of connection a "floating ground" to distinguish it from a ground that is actually connected to the chassis.

With one side of the voltage source connected to the ground, we make dc voltage measurements between the ground and various other points in the circuit. We then have a convenient method of indicating the voltage that should be found in various parts of the circuit.

An example of what this can lead to is shown in Fig. 4. Here we have shown a 15 volt battery connected to a small lamp. The positive terminal of the battery in Fig. 4A is numbered 1 and the negative terminal is numbered 2. Notice that connected to the negative terminal we have a lead going to a symbol that is marked ground. This is another new schematic symbol for you to remember.

We are going to start using an expression which may be new to you. It is "with respect to". It means simply "compared to" and is always used by electronics technicians. You will have no trouble if you know that "compared to" and "with respect to" mean the same thing.

In Fig. 4A the negative terminal of the battery is connected to ground. Using ground as a reference

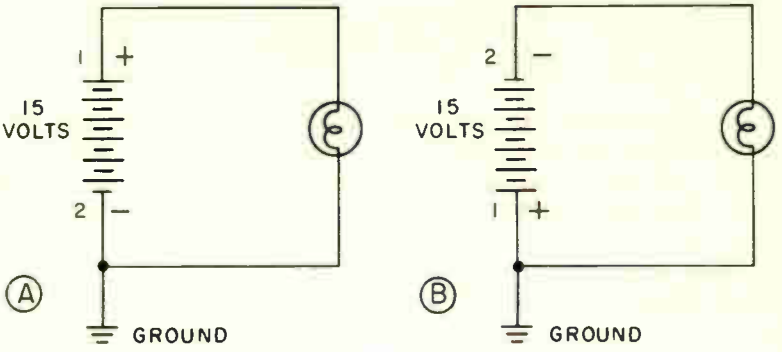


Fig. 4. Simple circuits with ground connections.

point we say that terminal 1 is +15 volts with respect to ground.

Now look at Fig. 4B. Here terminal 1 of the same battery, which is the positive terminal, is connected to ground. In this case using ground as a reference point we say that terminal 2 is -15 volts with respect to ground.

The important thing for you to understand in these two examples is that the voltage is the same in both cases. However, the polarity of the different points in the circuit will be positive or negative depending upon how the voltage source is connected to the circuit.

A 15 volt battery made up of 1-1/2 volt cells will have a total of ten cells. If the battery has a center connection, as shown in Fig. 5, and the center connection is connected to ground, we have a situation where we have both negative and positive polarities with respect to ground. Terminal 1 is + 7-1/2 volts with respect to ground and terminal 2 is - 7-1/2 volts with respect to ground. However, the total voltage is still 15 volts, as it was in both examples in Fig. 4, and the current flow through the bulbs would be the same in all three cases.

In your studies of electronic equipment you will run into equipment where the negative terminal of the voltage source is grounded as in Fig. 4A; you will run into equipment where the positive terminal is grounded as in Fig. 4B, and you will also encounter equipment where you have voltage both negative and positive with respect to ground as in Fig. 5.

AC VOLTAGE

You will remember that an ac voltage is one that causes an alternating current to flow. We refer to it as ac voltage instead of alternating current voltage. As in the case of dc voltage, we always use the abbreviation.

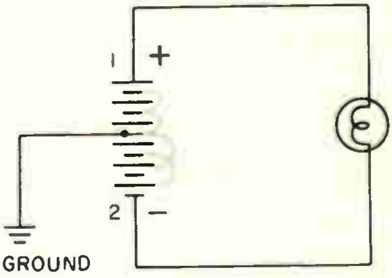


Fig. 5. A simple circuit where a voltage positive with respect to ground and a voltage negative with respect to ground are present.

Ac voltages are produced by generators or alternators. An alternator is a type of generator similar to the generator you studied earlier.

A schematic diagram of a simple ac circuit (similar to the dc circuit shown in Fig. 4) is shown in Fig. 6. Notice the symbol we have used to represent an ac generator. This is another important schematic symbol for you to remember.

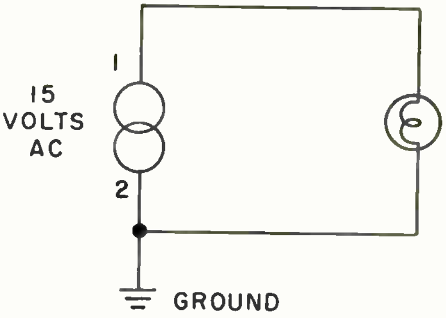


Fig. 6. A simple ac circuit with one side grounded.

In Fig. 6, terminal 2 of the generator is grounded. If we measure the voltage on terminal 1 with respect to ground or to terminal 2, we will get a voltage reading of 15 volts. The generator will produce an ac current flow that will have the same heating effect in the bulb as the 15 volt batteries did. However, you will remember that the voltage is continually varying. During one cycle, the voltage at terminal 1 starts at 0 as represented by point a in Fig. 7. The voltage begins to increase until it reaches its peak value at point b. If the rms or effective voltage is 15 volts then we know that the value of b will be 1.4 × 15 = 21 volts. Then the voltage between ground and terminal 1 begins to decrease until a half cycle after point a when we reach point c, where the voltage once again is 0. The voltage immediately begins to build up with the opposite polarity until we reach point d where once again the voltage between ground and terminal 1 is 1.4 × 15 = 21 volts. The voltage then begins to drop back until it reaches 0 again at point e.

The waveform between points a and e represents one complete cycle. The same cycle is completed again between points e and i, and then again between points i and m. In an ac circuit this cycle goes on indefinitely as long as the generator is operating.

During the first half cycle the voltage is positive at terminal 1 with respect to ground. During the next

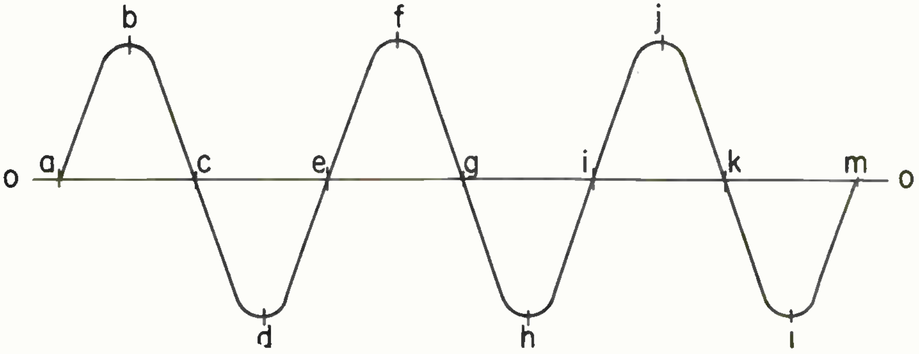


Fig. 7. Three cycles of an ac sinewave.

half cycle the voltage is negative with respect to ground. We draw the waveform above the line to represent a positive voltage and below the line to represent a negative voltage. We call the waveform between points a and b a quarter of a cycle; between b and c is also a quarter of a cycle as it is between c and d and d and e. The waveform between points a and c, points c and e, points e and g, etc., is referred to as a half cycle.

We said that we have a complete cycle between points a and e. By a complete cycle we mean the ac voltage starts at one point and goes through a complete cycle back to the equivalent point on the next cycle. We also have a complete cycle between points b and f because the waveform has gone through a full cycle between these two points. Between points c and g is also a full cycle as it is between points d and h. In speaking of a complete cycle we can start at any point on the cycle and continue on to the equivalent point on the next cycle. However, it is usually more convenient to start at a 0 point such as either point a or c when referring to a complete cycle. In fact, in most cases when speaking of an ac cycle we will start at point a and refer to the positive half of the cycle first and then the negative half. There is no reason why we have to do this; it is just something that is done by custom.

Notice the difference between the polarity at terminal 1 with respect to ground in Fig. 6 and the polarity of the ungrounded terminal in Figs. 4A and 4B. In Fig. 4A terminal 1 is the ungrounded terminal and it is always positive because the battery polarity does not change. In Fig. 4B, terminal 2 is the ungrounded terminal and it is always negative, again because the battery polarity does not change. In Fig. 6, terminal 1 is positive for one half cycle and negative for the next half cycle. Its polarity changes every half cycle because the voltage generated is an ac voltage. It is important for you to understand this difference between ac voltages and dc voltages.

VOLTAGES IN SERIES

Voltage sources can be connected in series. Whether they add together or subtract from each other depends upon the way in which they are connected.

In Fig. 8A we have shown two 4.5 volt batteries connected in series aiding. By this we mean that the two voltages add together. Notice that the batteries are connected together in the same way as the cells forming the battery are connected together. The positive terminal of the lower battery is connected to the negative terminal of the upper battery. With the arrangement shown in Fig. 8A the negative terminal of the lower battery is at ground potential. The voltage between terminal 1 and ground will be equal to the sum of the voltages of the two batteries, which in this case will be 9 volts.

In Fig. 8B, we have shown batteries with different voltages connected in series aiding. Notice that the positive terminal of the one battery is connected to the negative terminal of the other. The voltage between terminal 1 and ground will be the sum of the two battery voltages which is 7.5 volts. The position of the two batteries could be reversed; the voltage between terminal 1 and ground or terminal 2 would be the same in either case.

In Fig. 9, we have shown three examples of batteries connected in

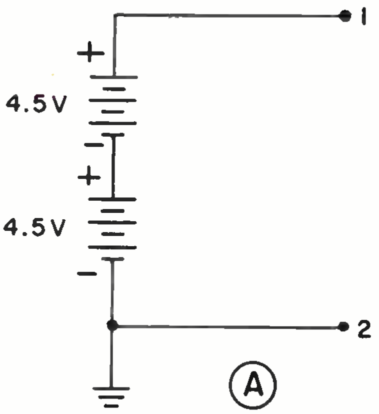


Fig. 8. Batteries connected in series so their voltages add.

series opposing. These batteries are connected so that their voltages oppose, and to find the total voltage we must subtract the battery voltages.

In Fig. 9A, each battery is a 4.5 volt battery. When you subtract 4.5 from 4.5 the result is 0 and therefore the potential between terminals 1 and 2 or between terminal 1 and ground is 0. The two batteries have equal voltages and therefore their voltages cancel.

In Fig. 9B, we have batteries of unequal voltages connected to oppose each other. The lower battery has a voltage of 3 volts, and the upper battery a voltage of 4.5 volts. Subtracting 3 from 4.5 gives us 1.5 volts. Since the upper battery has the higher potential, the voltage at terminal 1 will be positive with respect to ground or terminal 2. In other words, this voltage is able to overcome the voltage of the 3 volt battery and cause terminal 1 to be +1.5 volts with respect to ground.

In Fig. 9C, we have the opposite situation. Here the two batteries again subtract to give us a voltage

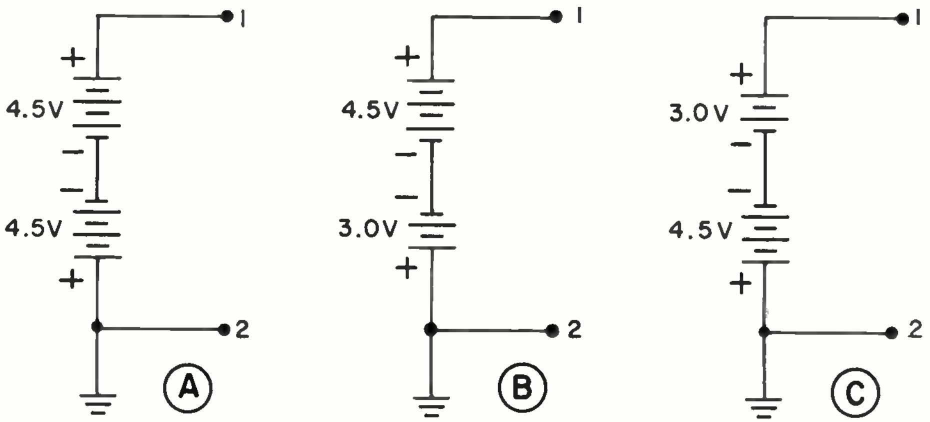


Fig. 9. Batteries connected in series so their voltages subtract.

of 1.5 volts. However, in this case, the polarity of the 4.5 volt and 3 volt batteries is reversed, so that now terminal 1 becomes -1.5 volts with respect to ground.

From the preceding examples you can see that batteries connected in series can either aid or oppose each other depending upon how they are connected. You will also see that when one side of the circuit is grounded, the other side can be either positive or negative depending upon the battery voltages and how they are connected. When unequal batteries are connected in series opposing, the polarity of the circuit will be the polarity of the battery with a higher voltage. When batteries are connected in series aiding, the polarity will be the same as the polarity of both batteries, since they must be connected in the same way in order to aid.

We can connect dc generators in series in exactly the same way as the batteries shown in Figs. 8 and 9 are connected. If they are connected in series aiding so that the negative terminal of one generator is connected to the positive terminal of the other, the total voltage available from the series combination will be the sum of the two voltages. If they are connected in series opposing so that the negative terminals of the generators or the positive terminals of the two generators are connected together, the voltage available will be the difference in voltage between the two generators, and the polarity of the circuit will be the polarity of the generator producing the higher voltage.

It is also possible to connect a battery in series with an ac generator such as shown in Fig. 10. Here, since the polarity of the voltage produced by the ac generator reverses every cycle we have a situation where during one half cycle the voltage produced by the generator will aid the battery voltage, and during the next half cycle the voltage will oppose the battery voltage.

In Fig. 11A, we have shown a graph of what the voltage will look like between terminals 1 and 2 of Fig. 10A when the peak voltage generated by the generator is exactly equal to the battery voltage. Terminal 2 is grounded and therefore is shown as zero voltage. The voltage at terminal 1 with respect to terminal 2 is shown

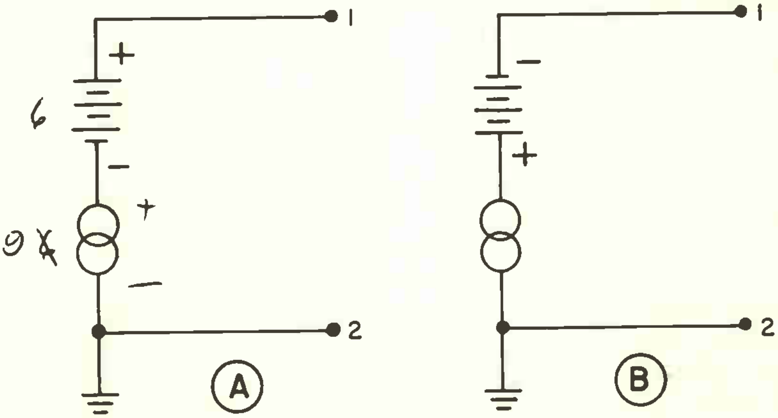


Fig. 10. Battery connected in series with ac generator.

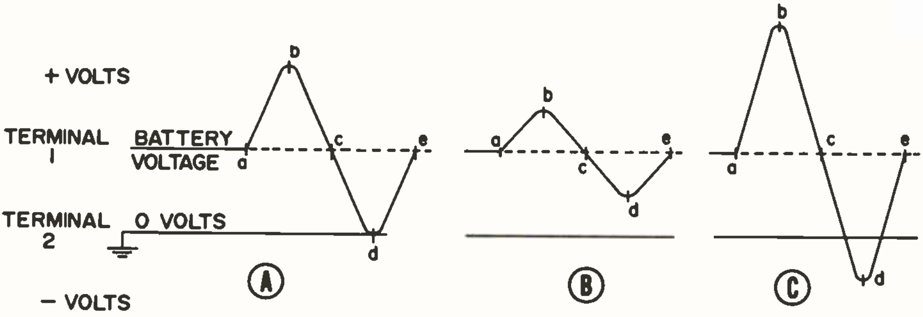


Fig. 11. Waveform showing how battery and generator voltages add in Fig. 10A. Voltage between terminal 1 and ground is shown.

by the graph. In electronics, as we have already pointed out, the expression "with respect to" means "compared to".

At the left of the graph in Fig. 11A, before the generator begins to turn, the voltage between terminals 1 and 2 will be the battery voltage. Terminal 1 is positive with respect to terminal 2 because the positive terminal of the battery is connected to terminal 1. When the generator begins to turn at point a in Fig. 11A, the generator voltage begins to build up during the first quarter cycle and adds to the battery voltage. When the generator voltage reaches its peak value at point b, the voltage between terminals 1 and 2 will be twice what it was at point a. This is because the peak generator voltage is adding to the battery voltage.

During the next quarter cycle, the generator voltage is falling from point b to point c. At the end of the first half cycle, the generator voltage will be zero as shown at point c, so the voltage between terminals 1 and 2 will be the battery voltage alone.

During the next quarter cycle, as shown between points c and d in Fig. 11A, the generator voltage begins to build up again, but this time the polarity of the generator voltage is reversed so it opposes the battery voltage. At point d, at the end of the third quarter cycle, the generator voltage will be exactly equal to the battery voltage but will have the opposite polarity. As a result, the two voltages will subtract, so at point d the voltage between terminals 1 and 2 will be zero. The actual voltage on terminal 1 at point d will be zero.

During the next quarter cycle, from point d to point e, the generator voltage decreases (becomes less negative) so that at the end of the cycle, at point e, the generator voltage is back to zero, and the voltage at terminal 1 is once again equal to the battery voltage.

In Fig. 11B, we have shown a situation in which the peak generator voltage is only half the battery voltage. Under these circumstances, the voltage builds up during the first quarter cycle. At point b, the total voltage between terminal 1 and terminal 2 will be 1-1/2 times the battery voltage. At point c on the curve, at the end of a half cycle, the generator voltage will be back to zero so the voltage between terminal 1 and ground (or terminal 2) will be equal to the battery voltage.

During the next half cycle, when the generator voltage begins to oppose the battery voltage, the voltage between terminals 1 and 2 drops until at the peak of the negative half cycle the voltage between terminals 1 and 2 is half the battery voltage. This is illustrated at point d in Fig. 11B.

As the ac voltage drops back to zero during the final quarter cycle, the voltage at terminal 1 increases back to the battery voltage as shown at point e.

In Fig. 11C, the peak generator voltage is 1-1/2 times the battery voltage. At the end of the first quarter cycle (at point b) the voltage between terminals 1 and 2 will be 2-1/2 times the battery voltage consisting of the generator voltage, which is 1-1/2 times the battery voltage, plus the battery voltage. At the end of the first half cycle (at point c) the generator voltage will be back to zero and the voltage between terminals 1 and 2 drops back to the battery voltage.

The peak generator voltage overcomes the battery voltage during the next half cycle because it is greater than the battery voltage and has the opposite polarity. As a result, at point d on the graph, terminal 1 is negative with respect to ground and terminal 2. Since the peak generator voltage is 1-1/2 times the battery voltage, it will cancel the battery voltage and then swing terminal 1 negative to a value equal to half the battery voltage.

You can see from Fig. 11 that when an ac voltage and a dc voltage are connected in series, they aid during one half cycle and oppose during the other half cycle. If the peak generator voltage is equal to the battery voltage, the total voltage will drop to zero volts once each cycle and will swing up to a value which is twice the battery voltage once each cycle. If the generator voltage is less than the battery voltage, the total voltage increases above the battery voltage and drops to less than the battery voltage once each cycle. On the other hand, if the generator voltage is greater than the battery voltage, the total voltage will reach a value which is more than double the battery voltage during one half cycle. When the generator voltage opposes the battery voltage during the other half cycle, the polarity of the output voltage will reverse when the generator voltage exceeds the battery voltage.

In Fig. 12, we have shown the voltage between terminal 1 and terminal 2, which is connected to ground, with the generator and battery connected as in Fig. 10B. The peak generator

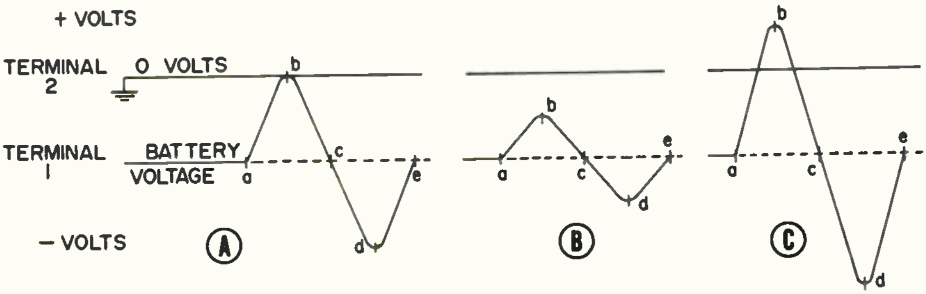


Fig. 12. Waveform showing how battery and generator voltages add in Fig. 10B. Voltage between terminal 1 and ground is shown.

voltage is exactly equal to the battery voltage in Fig. 12A, less than the battery voltage in Fig. 12B, and greater than the battery voltage in Fig. 12C.

When the peak generator voltage is exactly equal to the battery voltage, terminal 1 remains negative with respect to ground (terminal 2) at all times except when it drops to zero at the peak of the positive half cycle of the generator. When the peak generator voltage is less than the battery voltage as in Fig. 12B, terminal 1 remains negative with respect to ground (terminal 2) at all times. When the generator voltage is greater than the battery voltage as in Fig. 12C, terminal 1 becomes positive during a portion of the positive half cycle of the generator. For the remainder of the time, terminal 1 remains negative with respect to ground (terminal 2).

Having a battery and an ac generator connected in series is not much different from having two batteries connected in series except that in the case of the generator the polarity is changing each half cycle so that during one half cycle the two voltages aid and during the next half cycle the two voltages oppose. You can find the peak value that the two reach when they aid simply by adding the peak generator voltage to the battery voltage, and you can find the peak value that they reach when they oppose by subtracting the two. If the generator voltage is less than the battery voltage, then the voltage polarity in the circuit does not change. But if the generator voltage is greater than the battery voltage, the polarity of the voltage will change during the half cycle when the two voltages are opposing.

Why have we spent so much time explaining how voltages add or subtract? Do we ever make such connections in practical electronic circuits? This explanation was given to prepare you for actual circuits which will be described later. For example, in a tube or transistor we will have a fixed dc voltage so the part works properly. Then to this fixed dc voltage we will add a signal voltage, which is ac. The resulting combined voltage then becomes more negative or less negative (Fig. 12B) or more positive or less positive (Fig. 11B) and the tube or transistor can amplify the ac portion. This will be explained in greater detail later on. For the present, we just want you to know that there is a very practical reason for what you have just studied.

MILLIVOLTS

Just as the ampere is too large a current unit and we had to use milliamperes in some instances, so also is the volt sometimes too large a unit and we use the millivolt. A millivolt, abbreviated mv, is one thousandth of a volt. The prefix milli means the same when used with volts as it does with amperes - it means one thousandth. Therefore, to convert from volts to millivolts, you do the same thing as you did in converting from amps to milliamps. You multiply by 1000 - to do this you simply add zeros and move the decimal point three places to the right. To convert from millivolts to volts, you do the opposite; you divide by 1000 and to do this move the decimal point three places to the left. Remember, it is exactly the same as going back and forth between amps and milliamps. Thus, 2.5 volts = 2.5 × 1000 = 2500 millivolts; 49 millivolts = .049 volts.

MICROVOLTS

Sometimes even the millivolt is too large a unit and we use the microvolt, which is one millionth of a volt, just as the microampere is one millionth of an ampere.

To convert from volts to microvolts multiply by 1,000,000. You do this by moving the decimal point six places to the right. To convert from microvolts to volts you move the decimal point six places to the left, just as you did in converting microamps to amps.

You might wonder where such a small unit as the microvolt is used. It is sometimes used in measuring the strength of a radio or TV signal at a certain point. Also, in testing radio and television receivers, signals from a few microvolts are fed into the receiver and then measured at various points in the receiver to see how much the various stages are amplifying the signal. You might find that the signal at the input of one stage is 10 microvolts and at the output was 100 microvolts; this means that the stage amplified the signal voltage ten times. Technicians seldom have to convert back and forth between volts, millivolts and microvolts, as often as they do in the case of amps, milliamps and microamps. However, since the procedures for converting from one to the other are the same, if you know one, you know the other.

You will remember that to convert from milliamps to microamps you moved the decimal point three places to the right, and to convert from millivolts to microvolts you do the same thing. Similarly, to convert from microvolts to millivolts you move the decimal point three places to the left.

THE KILOVOLT

A unit that you will encounter in voltage measurements is the kilovolt. The kilovolt is one thousand volts. Thus 25 kilovolts, which is often abbreviated 25 kv, is equal to 25,000 volts. You will run into high voltages of this type in television receivers. Black and white television receivers often use voltages of 15 kv or more (15,000 volts) to operate the picture tube. In color television receivers some will have voltages as high as 25 kv. Just remember that a kilovolt is equal to 1000 volts, so to convert kilovolts to volts, you simply multiply by 1000.

SUMMARY

You should remember the important differences between ac and dc voltages. A dc voltage, which is produced by a battery or a dc generator, will have a polarity that does not change. Connected to a circuit, a dc voltage source produces a current which flows in one direction. An ac voltage changes potential (having one polarity during one half cycle and the opposite polarity during the next) and produces a current which flows in one direction during one half cycle and in the opposite direction during the next.

Voltages are often connected to common connections called grounds, and may be either positive or negative with respect to ground depending upon how they are connected to it.

Batteries and/or generators can be connected in series aiding so that their voltages add, or in series opposing so that they subtract. When connected in series between ground and another point, the polarity of the point may be positive or negative when the batteries oppose, depending on the polarity of the larger voltage source.

A dc voltage source such as a battery can be connected in series with an ac generator, and the two voltages will add during one half cycle and oppose during the next. The highest voltage produced is equal to the battery voltage plus the peak generator voltage. If one side of the circuit is connected to a common ground, the polarity in the circuit will not change unless the generator voltage is greater than the battery voltage. In this case, the polarity will change during the portion of the cycle when the voltages are opposing.

Some circuits you will encounter will have very small voltages; others will have very high voltages. Remember that the millivolt (abbreviated mv) is one thousandth of a volt, the microvolt (abbreviated µv) is one millionth of a volt, and the kilovolt (abbreviated kv) is one thousand volts.

SELF-TEST QUESTIONS

(z) If in the circuit shown in Fig. 4B, the battery is a 45 volt battery, what voltage is present at terminal 2 with respect to ground?

(aa) If in the circuit shown in Fig. 5, the battery is a 90 volt battery, and the ground terminal is a center tap, what is the voltage at terminal 1 with respect to ground? What is the voltage at terminal 2 with respect to ground?

(ab) In the circuit shown in Fig. 6, if the rms value of the voltage is 20 volts, what will the peak voltage be between terminal 1 and ground? Will it be positive or negative?

(ac) If a 15 volt battery and a 45 volt battery are connected in series as in Fig. 8B, what will the voltage be at terminal 1?

(ad) If two 22-1/2 volt batteries are connected in series as shown in Fig. 9A, what is the voltage at terminal 1 with respect to ground?

(ae) If two batteries are connected as shown in Fig. 9B, and one is a 45 volt battery and its positive terminal is connected to terminal 1, and the other is a 22-1/2 volt battery and its positive terminal is grounded, what will the voltage at terminal 1 be?

+
45v
−
−
22.5v
+

(af) If in Fig. 9C the positions of the two batteries are reversed so that the negative terminal of the 4.5 volt battery is connected to terminal 1, and the negative terminal of the 3 volt battery connects to ground, what will the voltage be at terminal 1?

(ag) If a generator that has a peak voltage of 15 volts is connected in series with a battery that has a voltage of 15 volts, what is the maximum voltage produced during the half cycle when the two aid, and what will be the minimum voltage produced when the two oppose?

(ah) If in the circuit shown in Fig. 10A the battery voltage is 15 volts and the peak generator voltage is 20 volts, what will the voltage be between terminal 1 and ground when they are aiding and when they are opposing?

(ai) If a generator and battery are connected as in Fig. 10B, and the battery voltage is 30 volts and the generator peak voltage is 45 volts, what will the voltage be between terminal 1 and ground when the two are aiding and when the two are opposing?

(aj) If a battery and generator are connected as shown in Fig. 10A and the battery voltage is 20 volts and the peak generator voltage is 10 volts what will the voltage be between terminal 1 and ground when they are aiding? When they are opposing?

(ak) If a battery and generator are connected in series as shown in Fig. 10B, and the battery voltage is 45 volts and the peak generator voltage is 30 volts, what will the voltage be between terminal 1 and ground when the generator reaches its peak value aiding the battery and when it reaches its peak value opposing the battery?

Resistance

One of the most important values you will work with in your electronic career is resistance. All wires and parts in electronic equipment have a certain amount of resistance. In some cases, such as in a short piece of copper wire, the resistance may be so low that it has no effect on the performance of the circuit. However, in every circuit there will be some part that has enough resistance to affect the operation of the circuit.

You know that when a voltage is applied to an electrical circuit a current will flow in the circuit. In a dc circuit, the thing that limits the amount of current that will flow for a given voltage is the resistance of the circuit. In an ac circuit, resistance also limits the current flow, but there may also be some other parts that will affect the current flow.

THE OHM

The unit of resistance is the ohm. It is named after the scientist George Simon Ohm who did a great deal of work in the early days when scientists first began studying electricity. If a voltage of 1 volt is applied to a circuit and a current of 1 amp flows in the circuit, the resistance of the circuit is 1 ohm. If a voltage of 2 volts is applied to a circuit, and a current of 1 amp flows, the resistance in the circuit is 2 ohms. Here we have twice the voltage applied to the circuit and, therefore, twice the force to force a current flow in the circuit. However, since the current flow is 1 amp in both cases, the circuit in the second case must offer twice the opposition to current flow. This is why the resistance of the circuit is 2 ohms.

In electronic equipment, the wires used to connect parts together have a very low resistance, usually only a fraction of an ohm. However, several of the parts that you have studied do have a much higher resistance. For example, a transformer has two or more windings on a common core. In the case of a transformer used to operate on a 60-cycle power line, there will be many turns on the primary winding of the transformer. The resistance will depend upon the size of the wire used on the primary winding of the transformer, but a resistance of about 100 ohms is typical of what you might find if you measured the resistance of the primary winding of the transformer used in a large radio or a small television receiver.

DC Resistance.

Dc resistance is the opposition offered to the flow of direct current in a circuit. If a dc voltage is applied to an electrical circuit, the dc resistance of the circuit will limit the current that will flow in the circuit. When we speak of dc resistance, we simply refer to it as resistance rather than by its entire name "dc resistance".

AC Resistance.

The ac resistance of a part may not be the same as the dc resistance. For example, at high radio frequencies, which are simply very high ac frequencies, the current flowing in a circuit has a tendency to flow on the outside of the conductor. This often causes the ac resistance to be somewhat higher than the dc resistance. In some coils used in very high frequency equipment you will find that the coils are silver plated. The purpose of the silver plating is to keep the resistance on the outside of the conductor as low as possible.

At power line frequencies and audio frequencies as well as low radio frequencies, the ac resistance of most parts is almost the same as the dc resistance and so we generally consider them as being the same. You will see later that it is comparatively easy to measure the dc resistance of a part, but it is much more difficult to measure the ac resistance.

Resistors.

While copper wire is used to connect electronic parts together to keep the resistance in the circuit low, there are some instances where we want resistance in the circuit. Parts made to put resistance in the circuit are called resistors. There are many different values and sizes of resistors used in electronic equipment, and several different types, but the most commonly used type is the "carbon resistor". This type of resistor is made of a mixture of powdered carbon and a cement-like material that is used to hold the carbon together. By varying the composition of the mixture, different values of resistance from a few ohms up to several million ohms can be obtained.

Carbon resistors come in several different sizes and in many different resistance values. The size of the resistor tells you how much power the resistor can handle. Three different sizes of carbon resistors are shown in Fig. 13. Each resistor has a resistance of 1000 ohms. The resistor in the middle can handle twice the power that the resistor on the top can handle. The resistor on the bottom can handle twice the power the resistor in the middle can, or four times the power the resistor

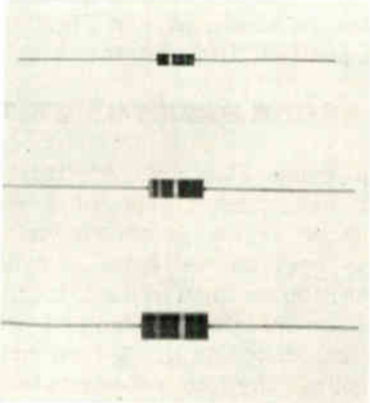
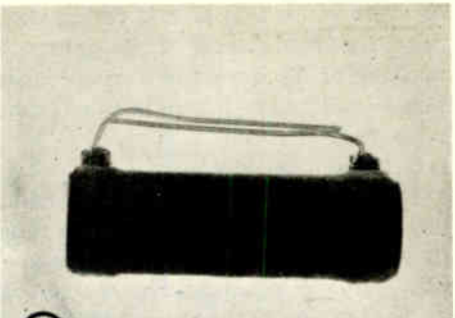


Fig. 13. Three 1000-ohm carbon resistors. The resistor at the top is a ½ watt size, the middle resistor, a 1 watt size and the bottom one, a 2 watt resistor.

on the top can handle. The resistor on the top is called a half-watt resistor, the one in the middle a one-watt resistor and the one on the bottom a two-watt resistor. The watt is a unit of electrical power, which you will learn about later.

Another type of resistor that you will encounter is the "wire-wound resistor". It is made of wire wound on a form, which is usually some type of ceramic form. The wire used to wind the resistor is called resistance wire; it gets its name because it has a much higher resistance than copper wire. Wire-wound resistors are used in places where they must handle a higher current than could be handled by a carbon resistor.

Another type of resistor that you will encounter is the deposited film resistor. This type of resistor has a metal oxide (a combination of a metal and oxygen) film deposited on a ceramic form. The advantage of this type of resistor is that it can be made to handle higher currents than a carbon resistor and at the same time can be made in larger resistance values than the wire-wound resistor. A wire-wound resistor is shown at A in Fig. 14 and a deposited film resistor at B.



Ⓐ WIRE-WOUND RESISTOR

Ⓑ DEPOSITED-FILM RESISTOR

Fig. 14. A wire-wound resistor is shown at A; a deposited film resistor at B.

LARGER RESISTOR UNITS

In many electronic circuits you will have resistances of several thousand ohms; in others you will have resistances over a million ohms. Rather than indicate the value of these resistors in ohms it is more convenient to use the K-ohm and the megohm. The letter K stands for one thousand so the K-ohm is one thousand ohms. Meg stands for one million so one megohm is one million ohms. Thus, rather than mark the value of a resistance as 2,200 ohms we would indicate the value as 2.2K. A resistor having a resistance of 100,000 ohms would be labelled 100K. A resistor with a resistance of 470,000 ohms would be marked 470K.

We use the unit megohms for resistors larger than one million ohms. A resistor whose value is 2,200,000 ohms would be labelled 2.2 megs or 2.2M; both abbreviations are used. Sometimes a resistor that is somewhat less than a megohm in resistance is also expressed in megohms. For example, a 470,000 ohm resistor could be labelled 470K, and it can also be labelled .47 megs or .47M. Any one of the three labellings could be used since they all mean the same thing.

Converting back and forth between ohms, K-ohms and megohms is essentially the same as converting between amps, milliamps and microamps. However, in this case remember that the ohm is the small unit, the K-ohm is one thousand ohms and the megohm is one million ohms. To convert from the small unit to the larger unit you simply move the decimal point to the left, either three places or six places, depending on whether you are converting to K-ohms or to megohms. To convert from the large unit to the small unit you move the decimal point in the opposite direction. As a technician you will have to convert values back and forth. The values of carbon resistors are identified by means of a color code. The color code will give the resistance in ohms, but the value may be given on a circuit diagram in K-ohms or megohms to save space. Thus you have to know what the different units mean so you will be able to identify them on circuit diagrams.

SUMMARY

Much of the material covered in this section of the lesson will be a review for you. However, resistance is a very important subject, and you should make sure you understand everything in this section before going on to the next. In the next section of the lesson you are going to study Ohm's Law.

The important points to remember in this section are that in a dc circuit the current flow in the circuit will be limited by the resistance in the circuit. In an ac circuit the resistance will also limit the current, but there may be some other factors that also aid in limiting the current.

The unit of resistance is the ohm. If a current of 1 ampere flows in a circuit when a voltage of 1 volt is applied to the circuit, the resistance in the circuit is 1 ohm.

Three important types of resistors that you will encounter in electronic equipment are the carbon resistor, the wire-wound resistor, and the metal oxide film resistor. These resistors are made in many different resistance values and in different sizes to handle different values of current.

In many electronic circuits the resistance is so high that we use the K-ohm, which is equal to one thousand ohms and the megohm which is equal to one million ohms. You should be able to convert from one unit to another so you will be familiar with all three units.

SELF-TEST QUESTIONS

(al) If the current flowing in a circuit is 1 amp, and we double the resistance in the circuit, will the current increase, decrease, or remain the same?
(am) Name the three types of resissistors that are used in electronic equipment.
(an) Convert 4,700 ohms to K-ohms.
(ao) Convert 5,600,000 to megohms.
(ap) Convert .330 megs to K-ohms.
(aq) Convert 2.2 megs to ohms.
(ar) Convert 8.2 K-ohms to ohms.
(as) Convert 680 K-ohms to megohms.
(at) Draw the symbol used to represent a resistance. You should remember this from an earlier lesson.

Ohm's Law

Ohm's Law is one of the most important laws or rules in electronics. It tells you how the voltage, current and resistance are related in an electrical circuit. Ohm's Law states that the current flowing in the circuit is equal to the voltage divided by the resistance. Rather than use words every time to express this law, we use symbols. We use the letter I for current, E for voltage and R for resistance. Using these symbols we can express Ohm's Law as:

$$I = E \div R$$

This is more often written in the form:

$$I = \frac{E}{R}$$

By using this expression, or by rearranging it mathematically, if we know any two of the three values, resistance, current or voltage, we can determine the other. As a radio television serviceman you will be concerned with replacing parts and will not have many occasions to work out the value of a part using Ohm's Law. However, an understanding of it will help you understand what is going on in the circuits you will study in this and in following lessons. A technician who wants to get his FCC license to work at a broadcasting or television station, or a technician who wants to work in industry or as an engineering aid will have to be able to work out problems involving Ohm's Law. We are going to use Ohm's Law to learn more about how voltage and resistance affect the current in a circuit. We will do some simple problems involving Ohm's Law. Be sure to follow these through carefully so you will understand what is happening in the circuits we discuss. We will work out each step in detail even though some of the steps may seem comparatively simple.

HOW VOLTAGE AFFECTS CURRENT

In Fig. 15 we have shown a simple circuit consisting of a voltage source and a resistor. The battery voltage, E = 20 volts; the resistance of the resistor, R = 2 ohms. Notice the symbol we have used to indicate ohms. This is the Greek letter omega and it is often used on diagrams as an abbreviation for ohms.

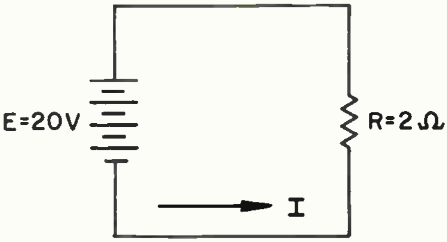


Fig. 15. A simple circuit consisting of a voltage source and a resistor.

We can determine the current that will flow in this circuit by using Ohm's Law. We simply take the formula and then substitute the values of E and R which we have and this will give us the value of I.

$$I = \frac{E}{R}$$

$$I = \frac{20}{2} = 10 \text{ amps}$$

Thus in the circuit shown in Fig. 15 the current flowing will be equal to 10 amps. If we increase the voltage to 40 volts, the new current flowing will be:

$$I = \frac{40}{2} = 20 \text{ amps}$$

and if we reduce the voltage to 10 volts, the current flowing in the circuit will be:

$$I = \frac{10}{2} = 5 \text{ amps.}$$

The important thing to see from the preceding is how the current flowing in the circuit with a given resistance in the circuit is tied directly to the voltage. Increasing the voltage increased the current, and reducing the voltage reduced the current. In the example where we doubled the voltage, the current doubled, and where we cut the voltage in half, the current was cut in half. This relationship will always hold true. If we increase the voltage to three times its original value, then the current will increase to three times the original value, and if we reduce the voltage to one third of its original value, then the current will be reduced to one third of its original value. We can say that in a given circuit the current will vary directly with the voltage. Any change in the voltage will result in a corresponding change in the current.

Notice that in the example given, the voltage was given in volts, the resistance was given in ohms and the current we calculated was in amps. In using Ohm's Law we must always use these basic units. Often this leads to a somewhat more difficult problem than shown in Fig. 15. Look at the example in Fig. 16.

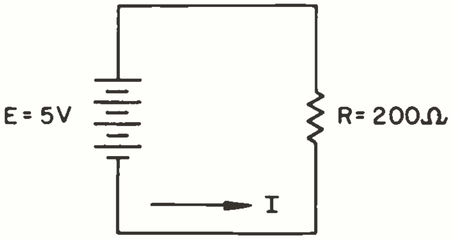


Fig. 16. A simple circuit where E = 5V and R = 200Ω.

In Fig. 16, the voltage is 5 volts and the resistance in the circuit is 200 ohms. Using Ohm's Law to determine the current we have:

$$I = \frac{5}{200}$$

Here the division is not quite as simple as it was in the preceding example because we have to resort to a decimal division. The division is not particularly difficult; it is shown in Fig. 17. We see that we get a current of .025 amps. We could leave our answer like this, or we can convert it to milliamperes by multiplying by 1000. To do this we simply move the decimal point three places to the right and get the answer, I = 25 ma.

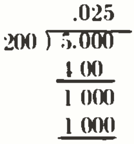


Fig. 17. Solution for I in Fig. 16.

Since our answer is in milliamperes, and we multiplied the current in amperes by 1000 to get our answer into milliamperes, if we want to avoid the decimal division we can multiply by 1000 before performing the division and get the answer directly in milliamperes. When we do this the problem becomes:

$$I = \frac{5}{200} \times 1000$$

$$I = \frac{5000}{200}$$

Now we can cancel two zeros above the division line and two below the line so we have:

$$I = \frac{50\cancel{0}\cancel{0}}{2\cancel{0}\cancel{0}} = \frac{50}{2}$$

$$I = 25 \text{ ma}$$

You can use whichever method you want in determining the current in a circuit of this type. If you multiply by 1000 before performing the Ohm's Law division, be sure to remember that your answer will be in milliamperes. Incidentally, sometimes we use mils as well as ma for an abbreviation of milliamperes. In the preceding problem we can say our answer is 25 mils.

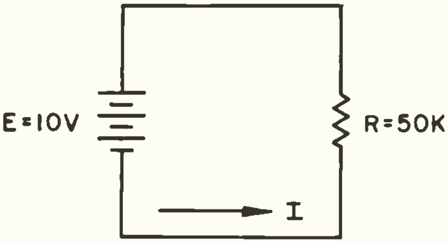


Fig. 18. A simple circuit where E = 10V and R = 50 K-ohms.

Another example is shown in Fig. 18. Notice that here we have an even larger resistor and also notice that the resistance is given in K-ohms. Let us see how we go about tackling a problem of this type.

You will remember we said that in using Ohm's Law the units must be in volts, amps and ohms. Therefore, the first thing we must do is to convert 50K-ohms to ohms. We do this simply by multiplying by 1000 and get a resistance of 50,000 ohms. Now using 50,000 ohms and 10 volts we can find the current using Ohm's Law.

$$\begin{array}{r} .0002 \\ 50000\,\overline{)\,10.0000} \\ \underline{10\ 0000} \end{array} \qquad \begin{array}{r} .2 \\ 50000\,\overline{)\,10000.0} \\ \underline{10000\ 0} \end{array}$$

Ⓐ Ⓑ

Fig. 19. Solution for I in Fig. 18.

$$I = \frac{E}{R}$$

$$I = \frac{10}{50{,}000}$$

Here again we have a decimal division. We can go ahead and perform this division as shown in Fig. 19A. We get as an answer .0002 amps. We can convert this to milliamperes by multiplying by 1000. To do this, we move the decimal point three places to the right and get .2 milliamps as the current. However, we still have a decimal so instead of converting to milliamps it would be more logical to convert to microamps. We do this by multiplying by 1,000,000 and this involves moving the decimal point six places to the right. We get as the current 200 μa.

If we want to avoid the decimal

division we can again convert before we perform the division. If we try converting to milliamps first by multiplying by 1000 we would have 50,000 divided into 10,000. This can be worked out as shown in Fig. 19B and we get our answer, .2 ma. However, since 50,000 is larger than 10,000 it is obvious that we have another decimal division and so to avoid this why not simply multiply the voltage, 10 volts by 1,000,000, and then get our answer directly in microamps. When we do this the formula becomes

$$I = \frac{10}{50{,}000} \times 1{,}000{,}000$$

$$= \frac{10{,}000{,}000}{50{,}000}$$

Notice that in 50,000 there are four zeros so we can mark these four zeros off and mark four zeros off from the ten million so that we will have

$$I = \frac{10{,}00\cancel{0}{,}\cancel{0}\cancel{0}\cancel{0}}{5\cancel{0}{,}\cancel{0}\cancel{0}\cancel{0}}$$

$$= \frac{1{,}000}{5}$$

$$= 200 \text{ microamps}$$

In electronic circuits you will frequently run into comparatively small voltages and very large resistances. This means that if you want to find the current flowing in the circuit and you divide directly, you will run into a decimal division. Therefore the easy way is to multiply by 1,000 or 1,000,000 first to convert the answer directly to milliamps or microamps. If you are doubtful about whether you should multiply by 1000 or 1,000,000, multiply by 1,000,000 and then perform the division. If your answer, which will be in microamperes, is over 1,000 microamperes you can convert this to milliamps if you want to by simply moving the decimal point three places to the left. However, it really doesn't matter whether you say that the current is 4,700 microamps or 4.7 milliamps, it means the same thing. For that matter, if you don't mind doing decimal divisions you don't have to convert at all. You can simply give the answer in amperes as .0047 amps. All three mean the same thing. If you like doing mathematics then the chances are that the decimal divisions won't bother you, but on the other hand if you are like most people and steer away from math, then multiplying either by 1,000 or a 1,000,000 first to convert the answer directly to milliamperes or microamperes is probably the easiest way to tackle problems of this type.

In examples shown in Figs. 15, 16 and 18, the voltage source was a battery and therefore the problems all involved dc voltage and current. If the voltage source had been an ac generator instead, we would have found the current in exactly the same way. In a circuit containing only resistance, Ohm's Law is used in exactly the same way in an ac circuit as it is in a dc circuit. Where the value of E is the rms value of the voltage, then the current will be found in its rms value. If the value of E given is the peak value of the voltage, and we use this value in Ohm's Law, then we will get the peak value of the ac current. If we want the rms value we can get it either by converting the peak value of the current to its rms value after we perform the calculation or we can convert the peak voltage to an rms value first.

HOW RESISTANCE AFFECTS CURRENT

In the simple circuit shown in Fig. 15 where the voltage is 20 volts and the resistance 2 ohms, we found by using Ohm's Law that the current flowing in the circuit is 10 amps. The same circuit is repeated in Fig. 20 except that we have replaced the 2 ohm resistor with a 4 ohm resistor. How will this affect the value of I? Using Ohm's Law we can find the current.

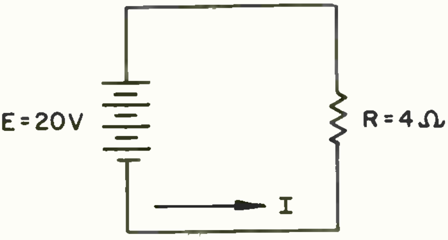


Fig. 20. The 2Ω resistor in the circuit of Fig. 15 is replaced by a 4Ω resistor.

$$I = \frac{E}{R}$$

$$I = \frac{20}{4} = 5 \text{ amps}$$

Here the current is 5 amps, half of what it was before. In other words, doubling the resistance cut the current in half. If instead of doubling the resistance, we had cut it in half so that R is equal to 1 ohm, then using Ohm's Law again we find that the current is equal to 20 amps. In other words, cutting the resistance in half has doubled the current. We will find that this relationship between current and resistance holds true regardless of how we change the resistance. If we increase the resistance to 3 times its original value, the current will be reduced to one third and if we cut the resistance to one third its original value the current will increase to three times its original value. We say that the current varies inversely to the resistance.

As a matter of fact, this relationship between current and resistance is obvious if we examine Ohm's Law. If we look at the expression for current

$$I = \frac{E}{R}$$

if E remains constant and we increase R, it is obvious that I must be smaller. Similarly, if we reduce R, and keep E constant, then I must get larger.

FINDING E

In some circuits we may know what the current flowing in the circuit and the resistance in the circuit are and have to find the voltage in the circuit. An example of this type of problem is shown in Fig. 21. Here the current is 2 amps and the resistance is 15 ohms. We want to find the value of E.

Ohm's Law can be rearranged mathematically into the form

$$E = I \times R$$

We usually drop the multiplication sign and simple write the formula as:

$$E = IR$$

The term IR means I × R; the multiplication sign is understood, even though it is not shown. Using this form of Ohm's Law we get:

$$E = 2 \times 15$$
$$= 30 \text{ volts}$$

Thus, the value of the voltage applied to the circuit must be 30 volts. If we want to, we can check this out using the other form of Ohm's Law:

$$I = \frac{E}{R}$$

substituting 30 for E and 15 for R we get a current of 2 amps, and since this agrees with the value given, the value of voltage which we determined must be correct.

Notice that the current in Fig. 21 is given in amps and the resistance in ohms. Sometimes the current may be given in milliamperes or microamperes and the resistance might be in K-ohms or megohms. In either case we must convert back to the basic units. Milliamperes and microamperes must be converted to amperes and K-ohms and megohms must be converted to ohms. An example of this type of problem is shown in Fig. 22. Here the current is given in milliamperes and the resistance in ohms.

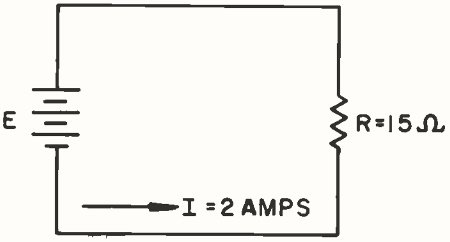


Fig. 21. A simple circuit where I = 2 amps and R = 15Ω.

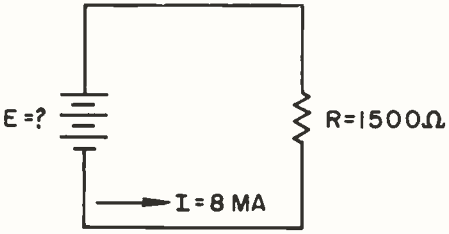


Fig. 22. Find E where I = 8 ma and R = 1500Ω.

Doing the problem shown in Fig. 22, we can first convert the current I which is 8 ma to amps by dividing by 1000. We do this by moving the decimal point three places to the left and get as the current, .008 amps. Now substituting these values in Ohm's Law we can find the voltage

$$E = IR$$
$$= .008 \times 1500$$
$$= 12 \text{ volts}$$

This involves a decimal multiplication, which is not too difficult to perform. However, if you want to avoid the decimal multiplication the easy way to do this is to simply write 8 milliamps as 8/1,000 amps. Now substituting the value of 8/1,000 in the formula we get

$$E = \frac{8}{1000} \times 1500$$

$$E = 8 \times \frac{1,500}{1,000}$$

$$E = \frac{12,000}{1,000}$$

Now cancelling three zeros above and below the division line we get

$$E = \frac{12,\cancel{0}\cancel{0}\cancel{0}}{1,\cancel{0}\cancel{0}\cancel{0}}$$

$$E = 12 \text{ volts}$$

If in Fig. 22 the resistance had been expressed in K-ohms it would be written 1.5 K-ohms. To convert this to ohms we multiply by 1,000. Instead of actually performing the multiplication we could then write the problem as:

$$E = \frac{8}{1,000} \times 1.5 \times 1,000$$

Now we can cancel the 1,000 above and below the division line and simply multiply 8 × 1.5 and our answer is 12 volts.

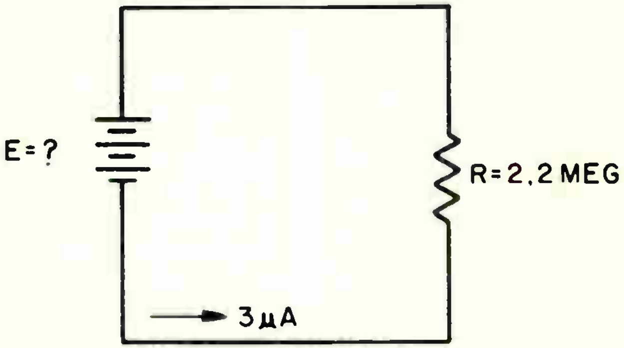


Fig. 23. Find E where I = 3 µa and R = 2.2 megohms.

In the example shown in Fig. 23 the current is given in microamps and the resistance in megohms and we have to find the voltage. We can convert microamperes to amperes by dividing the current by 1,000,000 and megohms to ohms by multiplying the resistance by 1,000,000. Thus substituting the formula:

$$E = I \times R$$

$$E = \frac{3}{1,000,000} \times 2.2 \times 1,000,000$$

$$= \frac{3 \times 2.2 \times 1,000,000}{1,000,000}$$

Here we simply cancel the 1,000,000 above and below the division line and multiply 3 × 2.2 and get our answer 6.6 volts. It is far simpler to do the problem this way than it is to convert to amps and ohms. These same techniques can be used regardless of what units the current and resistance are in. Remember that if the current is given in milliamperes simply write it over 1,000 and this will convert it to amps. If it is given in microamperes write it over 1,000,000 and this will convert it to amps. If the resistance is given in K-ohms multiply it by 1,000 to convert it to ohms and if it is given in megohms multiply it by 1,000,000 to convert it to ohms. Then before doing anything else look for numbers above and below the division line that can be cancelled and then perform the remaining multiplication.

FINDING R

We can rearrange Ohm's Law to find the resistance in a circuit if we know the voltage and the current. To do this we use Ohm's Law in the form:

$$R = \frac{E}{I}$$

Let us go back to the circuit shown in Fig. 15. Here the voltage is 20 volts and we found that the current is 10 amps. Now let us use Ohm's

Law to see what value of resistance we get using these values of voltage and current.

$$R = \frac{E}{I}$$

$$R = \frac{20}{10}$$

$$= 2 \text{ ohms}$$

As you see, the value obtained for the resistance is the value given originally so that we know that our calculation is correct.

When the voltage is given in volts and the current given in amps, determining the resistance in the circuit is quite simple. However, often the current will be in milliamps or microamps. In this case we must convert the current to amps in order to use the formula.

To convert milliamps to amps we divide by 1,000. We can do the same thing simply by multiplying the voltage by 1,000 and using the current in milliamperes in the formula. Thus the formula for resistance becomes

$$R = \frac{E \times 1{,}000}{I \text{ (in ma)}}$$

If the current is given in microamps we can multiply the voltage by 1,000,000 and then use the current in microamperes in the formula. Then the formula becomes

$$R = \frac{E \times 1{,}000{,}000}{I \text{ (in } \mu\text{a)}}$$

in microamperes.

Multiplying the voltage by 1,000 when the current is in milliamperes and by 1,000,000 when it is in microamperes eliminates the necessity of performing a decimal division. It is usually easier to divide by whole numbers and then multiply the result by either 1,000 or 1,000,000 than it is to perform the conversion to amperes first and then perform a decimal division. An example of a problem where the current is in milliamperes is as follows: find the resistance in a circuit where the voltage is 3 volts and the current is 3 milliamperes. Using the formula:

$$R = \frac{E \times 1{,}000}{I \text{ (ma)}}$$

$$R = \frac{3 \times 1000}{3}$$

$$R = 1000 \text{ ohms}$$

An example where the current is in microamperes is: find the resistance in a circuit where the voltage is 8 volts and the current 100 microamperes.

Using the formula:

$$R = \frac{E \times 1{,}000{,}000}{I \text{ (}\mu\text{a)}}$$

$$R = \frac{8 \times 1{,}000{,}000}{100}$$

the easiest way to do this problem is to divide the top and bottom by 100 simply by cancelling the 100 on the bottom and removing two zeros from the 1,000,000 and then we have

$$\begin{aligned} R &= 8 \times 10{,}000 \\ &= 80{,}000 \text{ ohms} \end{aligned}$$

SUMMARY

In this section of this lesson you have seen how the current in a circuit is affected by the voltage and the resistance in the circuit. We found that increasing the voltage increased the current and decreasing the voltage decreased the current. We said that the current varies directly as the voltage. In the case of the resistance in the circuit we found it had the opposite effect on the current. Increasing the resistance in the circuit decreases the current and decreasing the resistance increases the current. We say that the current varies inversely with the resistance.

We saw the three important forms of Ohm's Law and how you can use it in solving problems involving voltage, current and resistance in a circuit. If any two of these three quantities are known, you can use Ohm's Law to find the other.

You should remember the three forms of Ohm's Law. You will use them over and over again, so it would be worthwhile to take time now to memorize them. The three forms are:

$$I = \frac{E}{R}$$

$$E = IR$$

$$R = \frac{E}{I}$$

Remember that to use Ohm's Law the voltage must be in volts, the current in amps and the resistance in ohms. We showed you simple ways of getting around the problem of performing decimal operations in each type of problem. As you do the self-test questions do not hesitate to go back to the section of the lesson that dealt with the particular kind of problem you are working on and review how we worked the problem. It is not so important for you to memorize how to do these problems as it is to be able to do them with the aid of the examples given in the textbook. You will not be able to remember all you will learn about electronics either during your course or after you have completed your course, but the important thing is to remember the basic fundamentals and then know where to find the other facts that you may need.

If you find that you are puzzled by one of the self-test questions and you can't work it out even after reviewing the lesson, find the answer to the question at the back of the book and see how we did the problem. Then close the book and try to do the problem yourself and other problems of the same type without referring to the answers again. Don't be discouraged if you don't get the right answer every time or if you have trouble remembering the various forms of Ohm's Law at first. Make a determined effort to memorize them and after you have used them a number of times you will find that they will remain in your mind.

SELF-TEST QUESTIONS

(au) Give the form of Ohm's Law that is used when you know the voltage and the current and want to find the resistance.

(av) Write the Ohm's Law formula that is used when you know the current and resistance in a circuit and want to find the voltage.

(aw) Write the Ohm's Law formula used when you know the voltage and resistance in a circuit and need to find the current.

(ax) In a circuit such as Fig. 15, find the current if the voltage is 15 volts and the resistance is 3 ohms.

(ay) In a circuit like Fig. 15, find

the current if the voltage is 12 volts and the resistance is 6,000 ohms.

(az) In a circuit like Fig. 15 find the current if the voltage is 28 volts and the resistance 7,000 ohms.

(ba) In a circuit like Fig. 15 find the current if the voltage is 15 volts and the resistance 300 K-ohms.

(bb) Find the voltage in a circuit like the one in Fig. 21 where the current is 3 amps and the resistance is 6 ohms.

(bc) Find the voltage in a circuit like the one shown in Fig. 21 where the current is 20 ma and the resistance 1,000 ohms.

(bd) Find the voltage in a circuit like the one shown in Fig. 21 when the current is 18 ma and the resistance is 3K-ohms.

(be) Find the voltage in a circuit like Fig. 21 when the current is 47 μa and the resistance 200,000 ohms.

(bf) Find the voltage in a circuit like Fig. 21 when the current is 58 μa and the resistance 330K-ohms.

(bg) Find the voltage in a circuit like Fig. 21 when the current is 6 μa and the resistance 2 megohms.

(bh) In a simple series circuit if the applied voltage is 12 volts, and the current is 4 amps, what is the resistance in the circuit?

(bi) Find the resistance in the circuit if the applied voltage is 24 volts and the current 8 ma.

(bj) Find the resistance in the circuit if the applied voltage is 45 volts and the current flowing is 15 ma.

(bk) If the voltage applied to a circuit is 34 volts, and the current flowing is 170 μa, what is the resistance in the circuit?

(bl) If the voltage applied to a circuit is 144 volts, and the current flowing in the circuit is 120 μa, what is the resistance in the circuit?

(bm) Fill in the missing words in the following statement: if the voltage applied to a circuit is increased, the current will _____, and if the voltage applied to a circuit is decreased, the current will __________.

(bn) Fill in the missing words in the following: if the resistance in a circuit is increased, the current will ______, and if the resistance in a circuit is decreased, the current will _____.

ANSWERS TO SELF-TEST QUESTIONS

(a) 4 amps. If the original current was 1 amp and the number of electrons increased by four times the new current must be 4 amps.

(b) 3 amps × 1.4 = 4.2 amps.

(c) 7 amps × 1.4 = 9.8 amps.

(d) 7 amps ÷ 1.4 = 5 amps.

(e) 21 amps ÷ 1.4 = 15 amps.

(f) $6.00 = 600 cents.

(g) 350 cents = $3.50.

(h) 2 amps = 2000 ma. To perform the conversion we write 2 amps as 2.000 and then move the decimal point three places to the right and get 2000. In performing a conversion of this type, another way to look at it simply is adding three zeros.

(i) 6 amps = 6000 ma.

(j) 3.5 amps = 3500 ma. Again, we have simply moved the decimal point three places to the right; 3.5 amps = 3500 ma.

(k) .42 amps = 420 ma.

(l) .037 amps = 37 ma. Moving the decimal point three places to the right, we get 037, and since the zero has no significance we simply write the answer as 37 ma.

(m) .002 amps = 2 milliamps. Moving the decimal point three places to the right we get 002. ma and we drop the two zeros to the left of the 2 since they have no significance.

(n) 46 ma = .046 amps. Here we move the decimal point three places to the left. In order to do this we add a 0 to the left of the 4; thus 46 ma becomes .046 amps.

(o) 822 ma = .822 amps. To convert from the smaller unit to the larger unit we move the decimal point three places to the left.

(p) 1327 ma = 1.327 amps. Again, we simply move the decimal point three places to the left.

(q) 2 amps = 2,000,000 µa. To convert from amps to µa we have moved the decimal point six places to the right. To do this we must add the six zeros.

(r) .0017 amps = 1700 µa. Moving the decimal point six places to the right, we have to add two zeros to the right of the 7 in order to do this and .0017 can be written .001700 and then we move the decimal point six places to the right and get 1700 µa.

(s) 20 µa = .00002 amps. To convert from the smaller unit to the larger unit we move the decimal point six places to the left. In order to move it six places we have to add four zeros to the left of the 2.

(t) 147 µa = .000147 amps. Again, we add zeros to the left of the 1 and move the decimal point six places to the left to convert from microamps to amps.

(u) .26 ma = 260 µa. To convert from milliamps to microamps we move the decimal point three places to the right. In order to move it three places we have to add a zero to the right of the 6 so .26 ma becomes 260 µa.

(v) .031 ma = 31 µa. Again, to convert from the larger unit ma to the smaller unit microamperes we move the decimal point to the right. Thus, .031 ma becomes 031. µa. The 0 to the left of the 3 has no significance so we drop it and write the answer as 31 µa.

(w) 6100 µa = 6.1 ma. To convert from the smaller unit to the larger unit we move the decimal point to the left - thus when we move it three places to the left 6100 µa becomes 6.1 ma.

(x) 927 µa = .927 ma. Moving the decimal point three places to the left 927. µa becomes .927 ma.

(y) 327,000 µa = 327 ma. To convert from the smaller unit to the larger unit we move the decimal point three places to the left. Thus, 327,000 µa becomes 327 ma. To convert the 327 ma to amps we again move the decimal point three places to the left and get .327 amps.

(z) - 45 volts.

(aa) Terminal 1 is + 45V, and terminal 2 is - 45V.

(ab) The peak voltage between terminal 1 and ground will be 20 × 1.4 = 28 volts. It will be positive during one half cycle and negative the next half cycle.

(ac) + 60 volts. The two batteries are connected in series aiding, and therefore their potentials add, 15 + 45 = 60 volts. The terminal is positive because it's connected directly to the positive terminal of one of the batteries.

(ad) 0 volts. The two batteries are connected in series opposing and therefore the battery voltages subtract. Since both batteries are 22-1/2 volts the net value of the voltage between terminal 1 and ground will be 0.

(ae) + 22-1/2 volts. The two batteries are connected to oppose each other; thus their voltages subtract. 45V - 22-1/2V = 22-1/2V. The polarity will be that of the higher voltage battery, which is the 45 volt battery. Since its positive terminal is connected to terminal 1, then terminal 1 will be positive.

(af) - 1.5 volts. The two batteries are connected in series opposing and therefore their voltages subtract, 4.5 volts - 3 volts = 1.5 volts. The polarity will be that of the larger battery and since the negative terminal of the 4.5 volt battery connects to terminal 1, terminal 1 will be negative. Reversing the batteries had no effect on the polarity because we simply reversed their positions, keeping their polarities as shown in Fig. 9C. It makes no difference which position the battery is in insofar as the total voltage is concerned; as long as they are opposing each other you subtract to get the voltage produced by the two in series. In the circuit as shown in Fig. 9C, the polarity of terminal 1 is - 1.5 volts just as it is when the position of the two batteries is changed.

(ag) 30 volts when the two are aiding and 0 volts when the two are opposing. When the peak generator voltage has the same polarity as the battery voltage the total voltage will be the sum of the two voltages, 15V + 15V = 30V. When the generator has the opposite polarity to the battery, the two voltages will subtract. 15V - 15V = 0V.

(ah) +35 volts when they are aiding and - 5 volts when they are opposing.

When the peak generator voltage has the same polarity as the battery voltage, the two voltages add, 20V + 15V = 35V. When the two voltages oppose, the polarity of the generator will be - 20V with respect to terminal 1. Therefore the voltage between terminal 1 and ground will be 15V - 20V = - 5V.

(ai) - 75V when they aid and + 15V when they oppose. When the peak generator voltage has the same polarity as the battery voltage, the two voltages add. 30V + 45V = 75V. Since the negative terminal of the battery is connected to terminal 1, it will be - 75V with respect to ground. When the generator voltage opposes the battery voltage the peak voltage between terminal 1 and ground will be - 30V + 45V = + 15V.

(aj) + 30 volts when they are aiding and + 10 volts when they are opposing. When the peak generator voltage aids the battery voltage, the two voltages add. + 20V + 10V = + 30V. When the peak generator voltage opposes the battery voltage will have, + 20V - 10V = + 10V.

(ak) - 75V when they are aiding and

- 15V when they are opposing. When the two voltages have the same polarity their voltages add. 45 + 30 = 75V and since the negative terminal of the battery connects to terminal 1, terminal 1 will be negative. Another way of looking at this is to write the battery voltage as - 45V and the generator voltage as - 30V and add the two together. - 45V - 30V = - 75V. When the two voltages oppose the generator voltage subtracts from the battery voltage. 45V - 30V = 15V. Since the battery voltage is higher than the generator voltage the polarity of terminal 1 will be the polarity of the battery which is minus and therefore it will be -15V. Another way of doing this is to write the voltages down with their polarity. Here we have -45V + 30V = - 15V.

(al) The current will decrease. As a matter of fact, if we double the resistance in the circuit, the current will be cut exactly in half.

(am) Carbon resistors, wire-wound resistors and metal oxide film resistors are the three most widely used types of resistors in electronics.

(an) 4.7 K-ohms. To convert 4,700 ohms to K-ohms, you move the decimal point three places to the left. This is the same as dividing by 1,000 and getting 4.7 K-ohms.

(ao) 5.6 megohms. To convert 5,600,000 ohms to megohms you must move the decimal point six places to the left. This is the same as dividing by 1,000,000.

(ap) 330K-ohms. There are 1,000 ohms in a K-ohm and 1,000,000 ohms in a megohm. Therefore there must be 1,000 K-ohms in a megohm. To convert megohms to K-ohms you multiply by 1,000 and to do this you move the decimal point three places to the right. Thus, .330M = 330K.

(aq) 2,200,000 ohms. There are 1,000,000 ohms in a megohm and therefore to convert 2.2 megs to ohms you must multiply by 1,000,000. To do this you move the decimal point six places to the right.

(ar) 8,200 ohms. There are 1,000 ohms in a K-ohm and therefore to convert K-ohms to ohms, you multiply by 1,000. You do this by moving the decimal point three places to the right.

(as) .680 megohms. There are 1,000 K-ohms in a megohm and therefore to convert K-ohms to megohms you must divide by 1,000. To do this you simply move the decimal point three places to the left.

(at)

The symbol for resistance is shown above. There are probably more resistors used in electronics equipment than any other parts, so it is extremely important that you remember this symbol. The resistance of a resistor is usually indicated by writing the resistance either directly above or directly below the resistance symbol. The value may be given in ohms, K-ohms or megohms depending upon the size of the resistor. Usually the shortest form is used in order to conserve space on the diagram.

(au) $R = \frac{E}{I}$

(av) $E = IR$

(aw) $I = \frac{E}{R}$

(ax) 5 amps. To solve this problem you use the formula:

$$I = \frac{E}{R}$$

and substituting 15 volts for E and 3 ohms for R we get

$$I = \frac{15}{3}$$

$$= 5 \text{ amps}$$

(ay) The current will be 2 ma. We use the formula:

$$I = \frac{E}{R}$$

Since dividing 6,000 into 12 would be a decimal division, we can multiply by 1,000 and get our answer directly in milliamperes. When we do this we have:

$$I\ (\text{ma}) = \frac{12}{6{,}000} \times 1{,}000$$

$$I = \frac{12{,}000}{6{,}000}$$

and cancelling three zeros above and below the line we get:

$$I = \frac{12}{6}$$

$$= 2 \text{ ma}$$

(az) The current in this case will be 4 ma. You use exactly the same method as in the preceding example; since dividing 7,000 into 28 will involve a decimal division you can multiply by 1,000 and get your answer directly in milliamperes. In this problem we have:

$$I = \frac{28}{7{,}000} \times 1{,}000$$

$$I = \frac{28{,}000}{7{,}000}$$

and then cancelling three zeros above and below the line we have:

$$I = \frac{28}{7}$$

$$= 4 \text{ ma}$$

(ba) In this problem if we multiplied by 1,000 to get our answer in milliamperes, we would still have a decimal division because we must convert 300K to ohms by multiplying it by 1,000. Thus we would have:

$$I = \frac{15}{300 \times 1000} \times 1{,}000$$

The 1,000 above the division line would simply cancel the 1,000 below the division line and we would have to divide 300 into 15. So instead of converting our answer directly to milliamperes it would be better to convert to microamperes. Now the problem becomes:

$$I = \frac{15}{300 \times 1000} \times 1{,}000{,}000$$

$$I = \frac{15{,}000{,}000}{300{,}000}$$

and now cancelling five zeros above the line and five zeros below the line we have

$$I = \frac{150}{3} = 50\ \mu a$$

(bb) The voltage will be 18 volts. We use the formula:

$$E = IR$$

and substituting 3 amps for I and 6 ohms for R we get:

$$E = 3 \times 6$$
$$= 18 \text{ volts}$$

(bc) In this example the current is 20 ma, and we must convert this to amps. The easiest way to do this is to simply divide it by 1,000. Therefore we will substitute $\frac{20}{1000}$ for I in the formula and 1000 for R. Using the formula:

$$E = IR$$

$$E = \frac{20}{1000} \times 1{,}000$$

$$E = \frac{20{,}000}{1{,}000}$$

and now we simply cancel three zeros above the line and three zeros below the line and we get:

$$E = 20 \text{ volts}$$

(bd) In this problem, the current which is in milliamps must be converted to amps by dividing it by 1,000 and the resistance which is in K-ohms must be converted to ohms by multiplying it by 1,000. Using the formula to find the voltage we have:

$$E = \frac{18}{1000} \times 3 \times 1000$$

This can be written:

$$E = \frac{18 \times 3 \times 1000}{1000}$$

and now we simply cancel the 1000 above the line and the 1000 below the line and we get as our answer:

$$E = 18 \times 3$$
$$= 54 \text{ volts}$$

(be) In this example the current which is given in microamps must be converted to amps by dividing it by 1,000,000. Thus our problem becomes:

$$E = \frac{47}{1{,}000{,}000} \times 200{,}000$$

Now you can cancel five zeros above the line and five zeros below the line and we get:

$$E = \frac{47 \times 2}{10} = \frac{94}{10} = 9.4 \text{ volts}$$

(bf) In this example, the current which is in microamperes must be converted to amps by dividing it by 1,000,000, and the resistance which is given in K-ohms must be converted to ohms by multiplying it by 1,000. Thus using the formula to find the voltage we have:

$$E = \frac{58}{1{,}000{,}000} \times 330 \times 1{,}000$$

$$E = \frac{58 \times 330 \times 1000}{1{,}000{,}000}$$

We have four zeros above the division line so we can cancel four zeros below the line and then our problem becomes:

$$E = \frac{58 \times 33}{100}$$

and now multiplying 58 × 33 we get:

$$E = \frac{1914}{100} = 19.14 \text{ volts}$$

(bg) In this example the current, which is in μa, must be converted to amps by dividing it by 1,000,000, and the resistance which is in megohms, must be converted to ohms by multiplying it by 1,000,000. Thus to find the voltage we have:

$$E = \frac{6}{1{,}000{,}000} \times 2 \times 1{,}000{,}000$$

$$E = \frac{6 \times 2 \times 1{,}000{,}000}{1{,}000{,}000}$$

and now we can simply cancel the 1,000,000 above the division line with the 1,000,000 below the division line and our voltage becomes

$$E = 6 \times 2 = 12 \text{ volts}$$

(bh) 3 ohms. To solve a problem of this type we use the formula:

$$R = \frac{E}{I}$$

In substituting 12 volts for E and 4 amps for I we get:

$$R = \frac{12}{4}$$

$$= 3 \text{ ohms}$$

(bi) In this example, the current is given in milliamperes and we must convert it to amps. We can do this by multiplying the voltage by 1,000. When we do this we have:

$$R = \frac{24 \times 1{,}000}{8}$$

$$R = \frac{24{,}000}{8}$$

$$= 3{,}000 \text{ ohms}$$

(bj) We use the same procedure in this example as we did in the preceding example. We multiply the voltage by 1,000 and this is the equivalent of converting the current which is in ma to amps. Therefore our problem becomes:

$$R = \frac{45 \times 1{,}000}{15}$$

$$R = \frac{45{,}000}{15}$$

$$= 3{,}000 \text{ ohms}$$

(bk) In this example, the current is given in microamperes. To convert the current to amperes we can multiply the voltage by 1,000,000 and then proceed with our problem.

$$R = \frac{34 \times 1{,}000{,}000}{170}$$

$$R = \frac{34{,}000{,}000}{170}$$

$$R = \frac{3,400,000}{17}$$

$$= 200,000 \text{ ohms.}$$

(bl) This example is the same as the preceding example; the current is in microamperes and we must convert it to amps. We do this by multiplying the voltage by 1,000,000. Our problem therefore becomes:

$$R = \frac{144 \times 1,000,000}{120}$$

$$R = \frac{144,000,000}{120}$$

$$R = \frac{14,400,000}{12}$$

$$R = 1,200,000 \text{ ohms.}$$

If we wish to convert this value to megohms we can do so by dividing by 1,000,000, in which case our answer becomes 1.2 megs.

(bm) The completed statement, which is very important, is as follows: If the voltage applied to a circuit is increased, the current will increase, and if the voltage applied to a circuit is decreased, the current will decrease.

(bn) The complete statement, which describes how resistance affects the current in a circuit, is as follows: if the resistance in a circuit is increased, the current will decrease, and if the resistance in a circuit is decreased, the current will increase.

LOOKING AHEAD

You have reached a point where you have learned about voltage, current and resistance and have started to study simple circuits. You used the three forms of Ohm's Law in performing calculations in simple circuits.

In the next lesson, you will put some of these simple circuits together to form more complex circuits and you will see that even more complex circuits follow the same rules that were followed in these simple circuits. You have already come a long way in your studying of electronics and you will add considerably to your knowledge in the next lesson.

Lesson Questions

Be sure to number your Answer Sheet B103.

Place your Student Number on every Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time, or you may run out of lessons before new ones can reach you.

15 1. If a 9 volt battery and a 6 volt battery are connected in series aiding, what will the output voltage of the two batteries be?

3 2. If a 6 volt battery and a 3 volt battery are connected in series opposing, what will the output voltage be?

3. If a battery and a generator are connected as shown in Fig. 10A, and the battery voltage is 6 volts and the peak generator voltage is 6 volts, what will the maximum positive potential reached at terminal 1 be?

4. If in the circuit shown in Fig. 10A, the battery voltage is 6 volts and the generator peak voltage is 9 volts, will terminal 1 ever be negative with respect to ground - if so how much?

5. What are the three types of resistors commonly used in electronic equipment?

6. Give the three forms of Ohm's Law.

7. If the current flowing in a circuit is 2 amps, when the voltage is 50 volts, what will the current be if the voltage is reduced to 25 volts?

8. If the current flowing in a circuit is 50 ma when the resistance is 1,000 ohms, what will the current be if the resistance is reduced to 500 ohms?

9. If the voltage applied to a circuit is 4 volts, and the resistance in the circuit is 2,000 ohms, what will the current be?

10. If the current flowing in a circuit is 3 ma and the resistance is 6,000 ohms, what will the voltage be?

GETTING YOUR 'SECOND WIND'

After an opening burst of speed, a champion long-distance runner drops down to a steady natural pace. This brief period of relaxation releases that reserve of power called "second wind." He is then able to overtake and pass the now nearly exhausted leaders in the race.

No matter what you are doing, you can always do it better once you get your second wind. Instead of fighting that sleepy feeling which sometimes comes when you are studying, stop and relax for a few minutes so as to release your own supply of reserve power. Here are some ways to relax, all worth trying.

Get up and exercise for a few minutes. Get a drink of cold water. Step outside for a few deep breaths of fresh air. Take a brisk walk up and down the road or once around the block.

If you "shake yourself awake" in one of these ways, you'll find it isn't at all hard to get that second wind which enables you to study longer and makes the going easier. Then you'll get in some real worthwhile studying -- then you'll get things done!

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ACHIEVEMENT THROUGH ELECTRONICS

SERIES AND PARALLEL CIRCUITS

B104-1

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SERIES AND PARALLEL CIRCUITS

B104-1

STUDY SCHEDULE

By dividing your study into the steps given below, you can get the most out of this part of your NRI Course in the shortest possible time. Check off each step when you finish it.

☐ 1. **Introduction** . . . . **Pages 1 - 3**
In this section you learn the difference between series and parallel circuits.

☐ 2. **Series Circuits** . . . . **Pages 3 - 13**
You learn about resistance in series circuits and about voltage drops. You learn about the very important relationship between the voltage drops in a series circuit and the source voltage.

☐ 3. **Parallel Circuits** . . . . **Pages 13 - 21**
You learn how to find the resistance of a parallel circuit and you study voltage and current in parallel circuits.

☐ 4. **Series-Parallel Circuits** . . . . **Pages 21 - 31**
You learn how to solve problems involving series parallel circuit combinations.

☐ 5. **Answers to Self-Test Questions** . . . . **Pages 31 - 36**

☐ 6. **Answer the Lesson Questions.**

☐ 7. **Start Studying the Next Lesson.**

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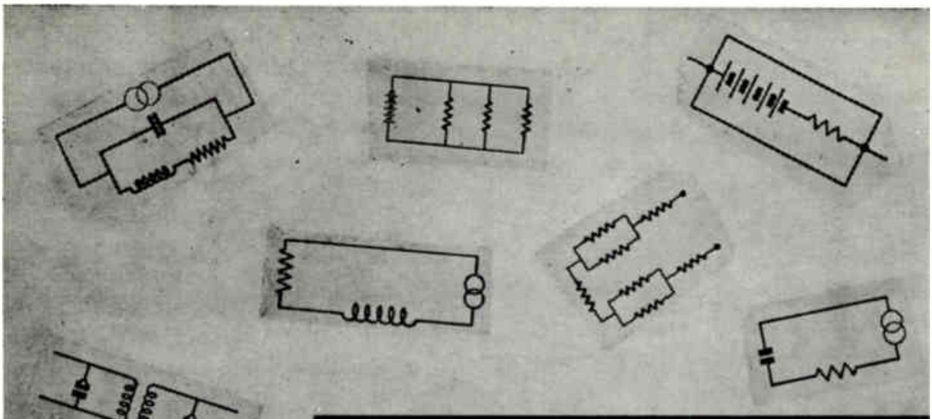

SERIES AND PARALLEL CIRCUITS

So far you have been studying relatively simple circuits. However, in spite of this, you have learned a great deal about electricity. You have studied voltage, current and resistance and the units that are used to measure them. You know that the units in which current is measured are the ampere, milliampere and microampere. The units used to measure voltage are the volt, the millivolt, the microvolt and the kilovolt. The units used to measure resistance are the ohm, K-ohm and megohm. You should be familiar with all these quantities at this time; you should know what they mean and how to convert from one unit to another.

You have also studied Ohm's Law and how it relates voltage, current and resistance. If you know any two of these values, you should be able to use Ohm's Law to find the third.

So far the circuits that you have studied have been relatively simple circuits. In almost all cases they have been series circuits. By a series circuit, we mean that the parts are connected so that there is only one path through which current can flow. In other words, if a resistor is connected between the negative and positive terminals of a battery, the electrons must leave the negative terminal of the battery, flow through the resistance to the positive terminal of the battery and then through the battery back to the negative terminal. There is only one path through which the current can flow.

There are other series circuits in addition to a circuit with only one resistor. A series circuit may have a number of resistors such as the circuit shown in Fig. 1. The circuit is called a series circuit, because like the simple circuits you have studied, the parts are connected in series so that electrons must flow first from the negative terminal of the battery through R_1, and then through R_2 and finally through R_3 back to the positive terminal of the battery and then through the battery back to the negative terminal. Electrons flow through one part after the other, in series. The series circuit is a very important circuit in elec-

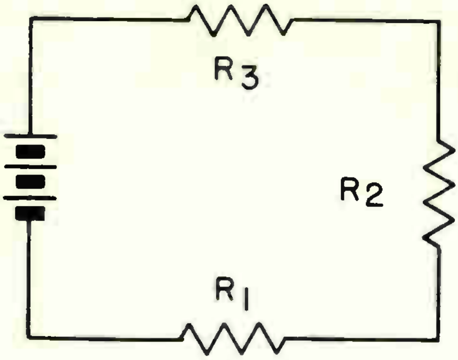

Fig. 1. A series circuit.

tronics; make sure that you understand what is meant by a series circuit.

In addition to a series circuit, we have what is known as a parallel circuit, such as is shown in Fig. 2. Here we have three resistors connected in parallel across the battery. We say that they are in parallel because there are three parallel paths through which current from the battery can flow. Electrons leaving the negative terminal of the battery can flow through either R_1, R_2, or R_3 and then back to the positive terminal of the battery and through the battery back to the negative terminal.

In this lesson you are going to study both series and parallel circuits. Both are important in electronics. Many circuits found in electronic equipment are series circuits; many circuits are parallel circuits. Some circuits are combinations of both series and parallel circuits.

When resistors are connected in series, such as in Fig. 1, you sometimes need to find the total resistance of the resistors. Similarly when they are connected in parallel as in Fig. 2, sometimes you have to find the effective value of the three resistors in parallel. We will learn how to do both in this lesson and you will learn how current flow is affected by connecting resistors both in series and in parallel.

In the first section of the lesson we will go into series circuits in considerable detail, and then in the second section we will go into parallel circuits. After we have completed both series and parallel circuits, we will study circuits that are combinations of both series and parallel circuits. As you may well realize, it is extremely important that you understand everything covered in series circuits first, and then what is covered in parallel circuits later. If there are some points that give you trouble, be sure to restudy the parts of the lesson you are in doubt about before going on. If you cannot work out the problem yourself, be sure to write to NRI and get additional help. If you do not master series circuits you will have trouble with parallel circuits. If you leave some points unclear in parallel circuits, then when you go on to study combinations of series and parallel circuits you will have difficulty with

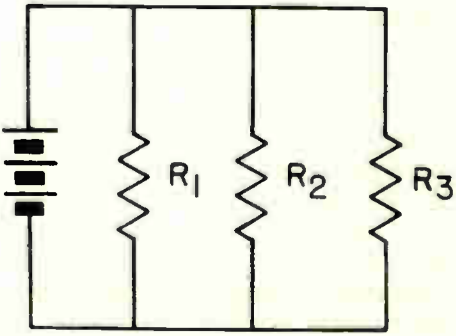

Fig. 2. A parallel circuit.

them. Learning electronics is simply a matter of taking one simple circuit at a time, learning how it works and then building on that knowledge. If you miss some of the basic fundamentals, you will have difficulty with more advanced circuits.

Be sure you can answer the self-test questions at the end of each section. These questions will test you on each section, and they are a good indication of whether or not you have mastered the material covered. Now, let us go ahead and study series circuits.

Series Circuits

A series circuit is a circuit in which there is only one path for electrons to flow. In a series circuit, such as we saw in Fig. 1, the current flowing is the same at all parts in the circuit. In other words, the current flowing through R_1 is equal to the current flowing through R_2; equal to the current flowing through R_3 and equal to the current supplied by the battery. The leads or conductors connecting the resistors and batteries together are also carrying the same current as is flowing through the resistors. This is one of the important things you should remember about a series circuit. There is only one path for electrons to flow, and the current flow in the circuit must be the same at all points in the circuit.

When we have resistors connected in a circuit such as in Fig. 1, we say that the resistors are connected in series. Now, let us see what effect these resistors connected in series have on the current flow in the circuit.

RESISTORS IN SERIES

In Fig. 3 we have shown a circuit that is identical to Fig. 1, except that in Fig. 3 we have given the battery a voltage of 15 volts and given each resistor a definite value. When the resistors are connected in series in this way, each resistor opposes the flow of current in the circuit. The total opposition to current flow will be equal to the sum of the resistances of the individual resistors. Thus, when resistors are connected in series, we can say that their total resistance is equal to the sum of the resistances. In this particular case we can express this mathematically as:

$$R_T = R_1 + R_2 + R_3$$

This formula can be used for find-

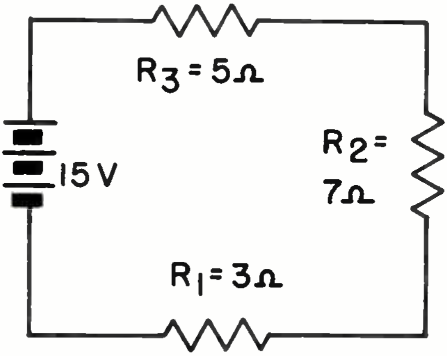

Fig. 3. A series circuit.

ing the resistance of any number of resistors connected in series. The total resistance is always equal to the sum of the individual resistors. Thus if you have five resistors connected in series and want to know the total resistance of the five in series you simply add the resistances together. Similarly, if there are ten resistors connected in series, to find the total opposition to current flow you simply add the value of the ten resistors together.

The opposition to current flow in the circuit will be equal to the total resistance of the resistors in series. In Fig. 3, the total resistance is:

$$R_T = 3 + 7 + 5 = 15 \text{ ohms}$$

Therefore, the three resistors connected in series offer the same opposition to current flow in the circuit as a single 15-ohm resistor would offer.

To find the current that will flow in the circuit you use Ohm's Law. You use it in the form:

$$I = \frac{E}{R}$$

When you have a number of resistors in series, R becomes the total value of these resistors, or R_T. In the circuit shown in Fig. 3, $R_T = 15$ ohms, and therefore in this circuit, the total current flow will be:

$$I = \frac{15}{15} = 1 \text{ amp}$$

The example given in Fig. 3 was comparatively simple, because the resistance values were all small and we did not get involved in any decimal divisions in finding the current. A somewhat more difficult example of a series circuit is shown in Fig. 4. However, this should not cause any more difficulty in finding the total resistance in the circuit than the example in Fig. 3, nor should it cause you any more difficulty in finding the total current flowing in the circuit, if you use the procedures you learned in the preceding lessons.

The first step in finding the total current that will flow in this circuit is to find the total resistance. To do this, you must convert all the resistance values to ohms. $R_1 = 1200$ ohms. $R_2 = 1.5$K-ohms. To convert this to ohms you multiply by 1000; thus 1.5 × 1000 = 1500 ohms. R_3 is given as 1800 ohms. R_4 is 1.2K-ohms, and again to convert this to ohms you multiply by 1000 and get 1200 ohms. Similarly, R_5 which is 3.3K-ohms is equal to 3300 ohms.

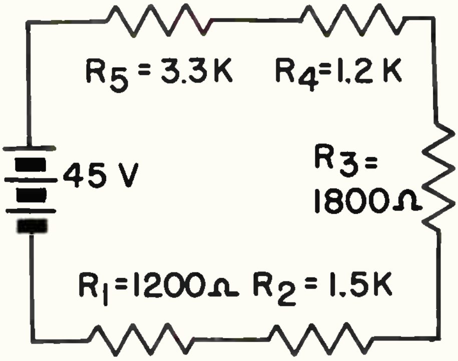

Fig. 4. A series circuit with five resistors.

Now you simply write down the values of these resistances as shown in Fig. 5, and then add the five values to get the total resistance in the circuit.

As shown in Fig. 5, the total resistance of the five resistors connected in series is 9000 ohms. Now, we use Ohm's Law to find the current that will flow in the circuit. We use the form,

$$I = \frac{E}{R}$$

If we substitute the values of 45 volts for the voltage, and 9000 ohms for the resistance, we will see that we immediately are involved with a decimal division. However, you will remember from the preceding lesson that you could multiply by 1000 and get the current directly in milliamperes. Once you do this the problem becomes:

$$I = \frac{45}{9000} \times 1000$$

and we can cancel three zeros above and below the division line so that our problem is

$$I = \frac{45}{9}$$

$$= 5 \text{ ma}$$

Any series circuit problem can be solved in the same way. To find the current flowing in the circuit you find the total resistance in the circuit and then divide this total resistance into the voltage applied. This will give you the total current flow in the circuit.

MEASURING VOLTAGES

Voltages are measured by means of an instrument called a voltmeter. To measure the voltage across a battery, a generator or a circuit, you connect the voltmeter directly across the part where you want to measure the voltage.

$$\begin{array}{r} 1200 \\ 1500 \\ 1800 \\ 1200 \\ \underline{3300} \\ 9000 \end{array}$$

Fig. 5. Total value of the five resistors in Fig. 4.

To measure dc voltages, you use a dc voltmeter. A dc voltmeter has one terminal marked with a minus sign and the other terminal marked with a plus sign. To measure the voltage across the battery shown in Fig. 6, you connect the minus terminal of the meter to the negative terminal of the battery and the plus terminal of the meter to the positive terminal of the battery. When you connect a meter across a 30-volt battery such as shown in Fig. 6, the meter pointer will move up the scale and indicate a voltage of 30 volts. Don't worry about how the meter works now - we will go into that later. The important point to see here is that you connect the minus terminal of the meter to the minus terminal of the battery and the plus terminal of the meter to the plus terminal of the battery.

Now looking at Fig. 6, you see that

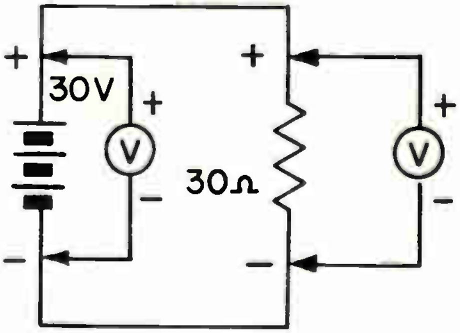

Fig. 6. Measuring voltage in a simple series circuit.

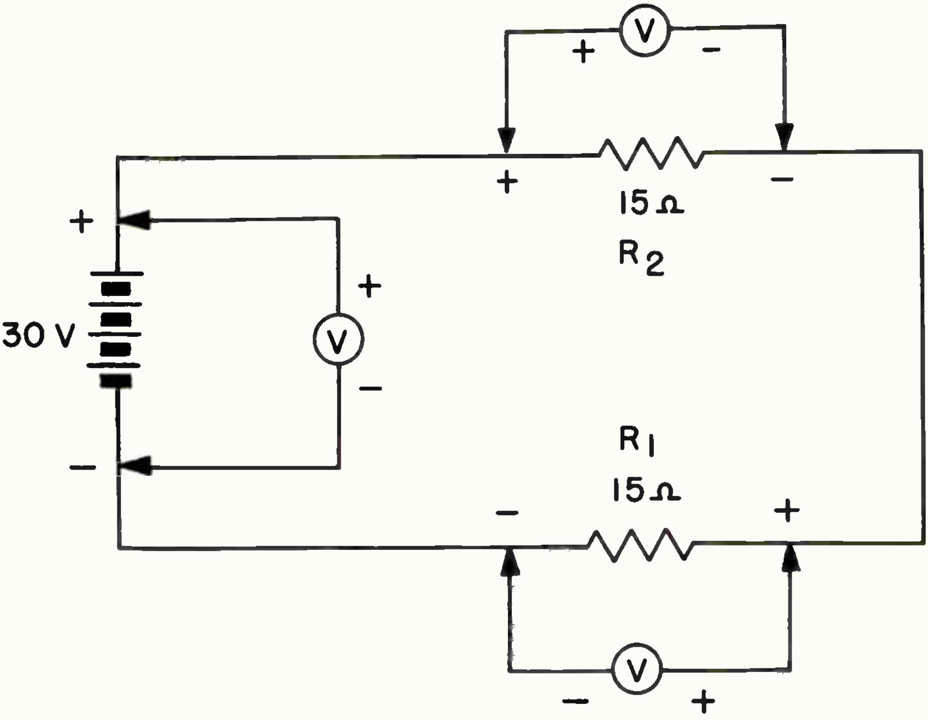

Fig. 7. Measuring voltage across series resistors.

the resistor is connected directly across the battery. Suppose we wanted to measure the voltage across the resistor, how would we do it?

Since the resistor is connected directly across the battery we would actually be reading the battery voltage if we connect the meter across the resistor. Therefore the meter must be connected across the resistor as shown in Fig. 6. The minus terminal of the meter must be connected to the end of the resistor that connects to the negative terminal of the battery and the plus terminal of the meter must be connected to the end of the resistor that connects to the plus terminal of the battery. Again, since the meter and resistor are both connected directly across the battery, the meter would indicate that the voltage was 30 volts.

Now, let us look at Fig. 7. Here, instead of a single 30-ohm resistor, we have two 15-ohm resistors connected in series across the 30-volt battery. Since the total resistance offered by the two 15-ohm resistors will be 30 ohms, insofar as the battery is concerned, the circuit will appear exactly like the one in Fig. 6. If we use Ohm's Law we would find that the current in both cases was 1 amp. If we measure the voltage across the battery, we connect the meter across the battery in exactly the same way as we connected it in Fig. 6.

If we want to measure the voltage across the two resistors in series, we would connect the negative terminal of the meter to the terminal of R_1 that connects to the negative terminal of the battery and the plus terminal of the meter to the terminal of R_2 that connects to the plus terminal of the battery. The meter would indicate 30 volts across the two resistors, because once again we are in effect simply connecting the meter across the battery. However, if the voltage across the two resistors in series is 30 volts, then it is logical to assume that the voltage across one resistor is only half this value or 15 volts. Indeed, if we connect the meter across R_1 we would find that the voltage is 15 volts, and if we can connect the meter across R_2 we would find that the voltage across R_2 is 15 volts.

To measure the voltage across one of these resistors, we connect the meter as shown. Notice that when measuring the voltage across R_1, the minus terminal of the meter must be connected to the end of the resistor that connects to the negative terminal of the battery, and the plus terminal of the meter is connected to the other end. This indicates that there is a voltage across R_1 having a polarity as shown in Fig. 7. To measure the voltage across R_2, we connect the meter with the plus terminal to the end of the resistor that connects to the positive terminal of the battery and the minus terminal of the meter to the other end of R_2. This indicates that the voltage across R_2 has the polarity shown.

We know that the current flow in this circuit will be 1 amp. We can prove that there should be a voltage of 15 volts across each of these resistors by using Ohm's Law. Ohm's Law states that if you know the resistance and current in a circuit you can find the voltage. You know that the resistance of R_1 is 15 ohms and you know that the current flowing through it is 1 amp. Putting these values in Ohm's Law we get:

$$E = IR$$

$$E = 1 \times 15 = 15 \text{ volts}$$

In the same way you could calculate the voltage across R_2 and you would find that it is also 15 volts. However, it is not necessary to do this because you know that the voltage across the series combination of R_1 and R_2 must be 30 volts since they are connected across the 30-volt battery, and that if the voltage across one of the resistors is 15 volts, the voltage across the other must be 15 volts also. In addition, in any circuit where you had equal resistors and the same current flows through the resistors, the voltage drops across the resistors must be equal.

We have taken this example one step further in Fig. 8. Here we have put three 10-ohm resistors in series across the 30-volt battery. Once again, you know that the total resistance in the circuit will be the sum of the individual resistors, which again is 30 ohms. Therefore the current flow in the circuit will be 1 amp and the voltage across each resistor will be 10 volts. To measure these voltages, you connect the meter across the individual resistors as shown. Notice that the negative or minus terminal of the meter always connects to the end of the resistor closest to the negative terminal of the battery and the positive or plus terminal of the meter connects to the end of the resistor closest to the positive terminal of the battery.

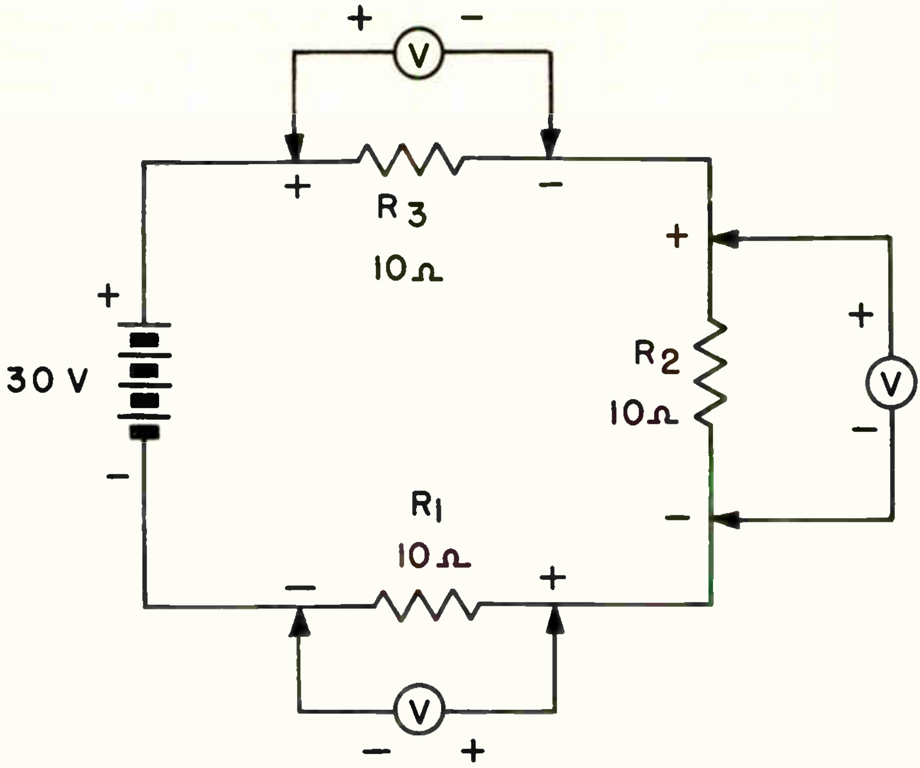

Fig. 8. Voltage polarities across three series resistors are as shown.

Across each resistor there will be a voltage, and in this case the voltage across each resistor will be 10 volts. The voltage across each resistor will have the polarity shown on the diagram.

VOLTAGE DROP

In referring to the voltage across the resistors in a circuit such as Fig. 8, we say that part of the voltage is used or dropped across each resistor. We refer to the voltage across a resistor as a "voltage drop". It is important that you remember this term, since we will use it over and over again. We say that the voltage is "dropped" across a resistor, and we refer to the voltage across each resistor as a "voltage drop".

In a series circuit such as the one shown in Fig. 8, the sum of the voltage drops will always be equal to the source voltage. This means that the voltage drop across R_1, plus the voltage drop across R_2, plus the voltage drop across R_3 will be equal to the battery voltage. This is true regardless of what the battery voltage is and regardless of the value of the resistors used in the series circuit. The sum of the voltage drops in a series circuit will always be equal to the source voltage.

Sometimes we have occasion to trace through a series circuit such as the one shown in Fig. 8 and record the voltages across the individual parts in the circuit. Let us do this starting at the minus terminal of the battery. The first part we come to is R_1 and the voltage across R_1 is 10 volts. Now the question becomes, should we write this as minus 10 volts or plus 10 volts? In tracing through the series circuit, we trace from the minus end of R_1 to the plus end. Let us say that all voltage encountered tracing from minus to plus will be indicated as positive voltages. Therefore the voltage drop across R_1 is + 10 volts. Now we come to R_2, and the voltage across it is also 10 volts. Since we are tracing from the minus end of the resistor to the plus end we indicate the voltage across this resistor as + 10 volts too. Next, we come to R_3 and the voltage across it is 10 volts and we are tracing it in the same way, from the minus end of the resistor to the plus end so we indicate this voltage as + 10 volts. Now as we continue to trace through the circuit we come to the positive terminal of the battery. Now we trace through the battery from the positive terminal to the minus terminal - in other words we are tracing through the battery in the opposite direction from which we traced through the resistors. Therefore since we have called the other voltages plus voltages, we must indicate this as -30 volts. Now if we add the voltages around the circuit we have

+ 10 volts + 10 volts + 10 volts - 30 volts =

+ 30 volts - 30 volts = 0

This brings us to another important rule or law in electronics known as Kirchhoff's Law. It states that the sum of the voltages in a closed circuit is 0. In other words, when you trace around a complete series circuit such as is shown in Fig. 8, and add the voltages with the proper polarity, the sum of these voltages will be 0. This is essentially the same as the statement that the sum of the voltage drops in the circuit will be equal to the source voltage. We have gone through both statements even though they are essentially the same, because you will run into both in your studies of electronics and it's important that you know what they mean and know that they are really saying the same thing.

Knowing that the sum of the voltage drops in a series circuit is equal to the source voltage will enable you to find the voltage across a resistor in an example such as the one shown in Fig. 9. Here you are given the

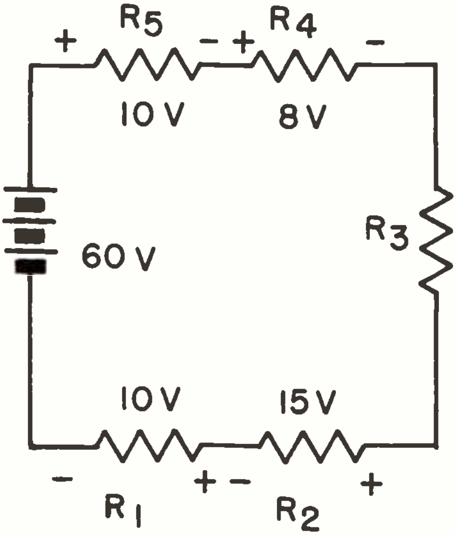

Fig. 9. The voltage across R_3 can be found in the above circuit.

source voltage as 60 volts. You are given the voltage across four of the resistors and want to find the voltage across R_3. You know that the sum of the voltage drops across the five resistors must be equal to 60 volts. So you add the voltage drops that are known across the four resistors. This will give you

$$10 + 15 + 8 + 10 = 43 \text{ volts}$$

Since the sum of the five voltage drops must be equal to 60 volts and the voltage drops across the four resistors total 43 volts, then you know that the voltage drop across R_3 must be equal to 17 volts.

Being able to work simple problems like this in series circuits will be helpful to you. In some electronic equipment parts may be buried in such a way that it is practically impossible to get at them with a voltmeter. You might want to measure the voltage across such a part. Sometimes, while it is impossible to get at the particular part across which you want to measure the voltage, you can measure the source voltage across this part and a number of other parts in series. Then if you can measure the voltage drop across the other parts and subtract these voltage drops from the source voltage, you can determine what the voltage drop is across the part in which you are interested. Being alert to such simple things as this is often what makes the difference between an expert technician who is able to get at the source of trouble in a piece of equipment quickly, and a technician who sort of blunders around trying first one thing and then the other, servicing more or less by a hit-and-miss procedure.

TUBE AND TRANSISTOR CIRCUITS

Often vacuum tube and transistor circuits are simple series circuits. In Fig. 10, we have shown two examples of such circuits. Looking at

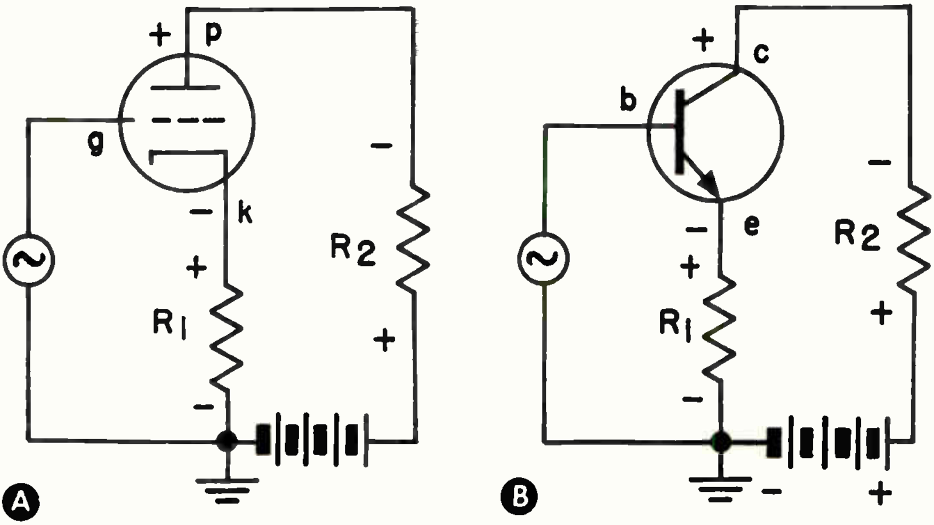

Fig. 10. A series tube circuit is shown at A; a series transistor circuit at B.

Fig. 10A first, here we see a triode vacuum tube. Some of the parts that are normally found in the circuit have been omitted for simplicity. The circuit that we are interested in is the series circuit made up of the battery, R_1, the tube and R_2. Electrons leave the negative terminal of the battery and flow through R_1 to the cathode of the triode tube. We use the letter k to designate the cathode. The cathode is heated to a red heat by the heater inside the cathode. (We have not shown the heater on the diagram because it is not part of the series circuit in which we are interested.) The electrons fly off the heated cathode and travel over to the plate of the tube. From the plate the electrons flow through R_2 back to the positive terminal of the battery and through the battery back to the negative terminal. Thus we have a series circuit consisting of R_1, the vacuum tube, R_2 and the battery. Across each of these parts there will be a voltage drop. The voltage drop across R_1 will have the polarity shown; the end that connects to the negative terminal of the battery will be negative and the end of the resistor that connects to the cathode of the tube will be positive. There will be a voltage drop between the cathode and the plate of the tube; the cathode will be negative and the plate positive. There will be a voltage drop across R_2, the end of the resistor that connects to the plate of the tube will be negative, and the end that connects to the positive side of the battery will be positive. By using a dc voltmeter and connecting it with the proper polarity we can actually measure these voltage drops, and if we use the right kind of meter so it will not upset the performance of the circuit, we will find that the sum of these voltage drops is equal to the battery voltage.

In Fig. 10B, we have shown a transistor circuit. We have also left out some of the parts in this circuit to simplify it. The series circuit we are interested in consists of R_1, the transistor, R_2, and the battery. In this circuit, electrons leave the negative terminal of the battery and flow through R_1 to the emitter (marked e) of the transistor. Here they flow from the emitter to the base (marked b), and from the base to the collector (marked c), and from the collector through R_2 back to the positive terminal of the battery, and through the battery back to the negative terminal. We have a series of voltage drops around the circuit as shown by the polarities marked on the diagram. Again, we can measure the voltage drop across R_1, the voltage drop between the emitter and collector of the transistor and the voltage drop across R_2, and the sum of these three voltage drops will be equal to the battery voltage.

These simple series circuits are typical of the series circuits you will find in all types of electronic equipment. You will find that the current flowing through these simple circuits is extremely important. The generator connected between the grid and ground of the tube circuit and between the base and ground in the transistor circuit causes the current through these circuits to vary, and this varying current is what makes it possible for the tube and the transistor to amplify the signal. The generator in each case is representing a small signal input, such as might be obtained from a microphone or from a preceding stage. An amplified signal will appear across R_2 in each case. We will go into detail on how these devices amplify later. The important thing for you to see at this time is the simple series circuits involved and to realize how important it is that you are able to recognize series circuits and remember the important facts about them.

SUMMARY

Series circuits are extremely important; you will find all kinds of them in electronic equipment. You must be able to recognize a series circuit. It is a circuit in which electrons leave the negative terminal of the voltage source and flow through a number of parts, one after the other, to the positive side of the voltage source and through the voltage source back to the negative terminal.

Remember what is meant by a voltage drop. It is the voltage that appears across any part in a series circuit. You must also be able to indicate the polarity of the voltage drop across a part. The end of the part that is closest to the negative terminal of the voltage source will be negative, and the end of the part that is closest to the positive terminal of the voltage source will be positive.

Remember the two important rules about the voltages in a series circuit. The sum of the voltage drops in a series circuit is equal to the source voltage. Another way of expressing the same rule is that if you add the voltages with the correct polarity, the sum of the voltages around a series circuit will be equal to 0.

If there are any parts of the preceding section that are not clear to you, it would be worthwhile to go over the entire section again, before trying the self-test questions. These early lessons are the most important lessons in your course. A thorough understanding of basic circuits will help you all the way through your course; it will make later lessons comparatively easy. On the other hand, if you do not understand these basic circuits, then you will have difficulty all the way through your course. After you have mastered the material covered in this section answer the self-test questions. If you find that you cannot answer one of the self-test questions, don't hesitate to go back and review. These questions are put in the lesson to help you determine whether or not you know as much as you should about the section. By going back and finding the answer to a self-test question that you cannot answer, you will be reviewing a part of the lesson that is not clear to you. This will help you master the important parts of the lesson.

SELF-TEST QUESTIONS

(a) What is a series circuit?

(b) How do you connect a dc voltmeter to a battery to measure the battery voltage?

(c) Draw a simple series circuit consisting of a battery and three resistors. Label the resistor that connects to the negative terminal of the battery R_1, and the resistor that connects to the positive terminal of the battery R_3. Label the resistor between R_1 and R_3, R_2.

(d) Indicate the polarity of the voltage drops across the resistors in the series circuit you have drawn.

(e) If R_1 equals 3 ohms, R_2 equals 4 ohms and R_3 equals 5 ohms, what is the total resistance of the three resistors connected in series?

(f) If the total current flowing in your series circuit is 2 amps, find the voltage drop across each of the three resistors in the circuit.

(g) What is the source voltage in the series circuit you have drawn?

(h) In a series circuit in which four resistors are connected across a battery, the battery voltage is 35 volts. The voltage drop across one resistor is 5 volts, across another resistor it is 7 volts, and across a third resistor it is 10 volts. What is the voltage drop across the fourth resistor?

(i) In a vacuum tube circuit such as shown in Fig. 10A, the voltage drop across R_1 is 3 volts, the voltage drop across R_2 is 125 volts, and the source voltage is 250 volts. What is the voltage between the plate and cathode of the tube?

(j) In a transistor circuit such as shown in Fig. 10B, the voltage drop across R_1 is .2 volts. The voltage drop across R_2 is 3.6. volts. The battery voltage is 6 volts. What is the voltage drop between the emitter and collector of the transistor?

(k) Draw a series circuit with a battery and five resistors like the one shown in Fig. 4. R_1 equals 120 ohms, R_2 equals 150 ohms, R_3 equals 180 ohms, R_4 equals 120 ohms and R_5 equals 330 ohms. The battery voltage is 18 volts. Find the total resistance in the circuit and then find the current flowing in the circuit, and finally find the voltage drop across each resistor and label the polarity of the voltage drop.

Parallel Circuits

You might think of a parallel circuit as the opposite of a series circuit. In a series circuit, current flows through one part after the other in the circuit. There is only one path for current flow and the current is the same in all parts of the circuit. In a parallel circuit, a different current can flow through each branch of the circuit. If two resistors are connected in parallel there are two paths through which current can flow; if three resistors are connected in parallel then there are three paths through which current can flow, and the current flowing in each path or branch of the circuit can be different.

Parallel circuits might seem a little confusing at first, but actually they are quite simple even though there are some important rules

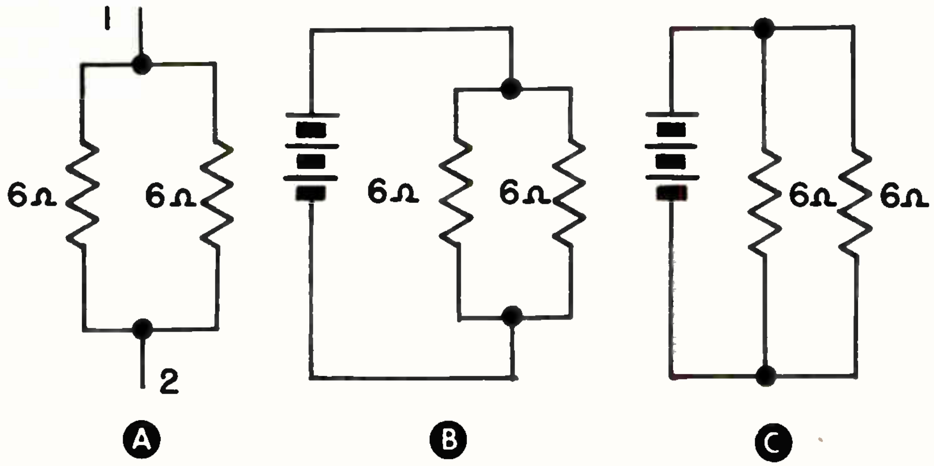

Fig. 11. Simple parallel resistor circuits.

which govern their performance. Once you learn these rules you will see that parallel circuits are no more difficult to understand than series circuits.

In the preceding section we learned that when two resistors were connected in series that their total resistance was equal to the sum of their resistances. We have a somewhat different situation in parallel circuits, so let us see exactly what happens.

RESISTORS IN PARALLEL

Often in electronic equipment two or more resistors may be connected in parallel. We need to be able to find the effective resistance of two resistors connected in parallel.

In Fig. 11A, we have shown two 6-ohm resistors connected in parallel. Between terminals 1 and 2 of these resistors there will be some net value of resistance. We can connect these two resistors in parallel across a battery as shown in Fig. 11B, and a certain current will flow in the circuit. The current that will flow in the circuit will depend upon the battery voltage, and the net resistance of the two resistors connected in parallel.

We can see better what is happening if we redraw the circuit as shown in Fig. 11C. Here we see clearly that each resistor is connected directly across the battery. Therefore there will be a current path from the negative terminal of the battery to the first 6-ohm resistor, through this resistor, and back to the positive terminal of the battery. The amount of current that will flow will depend upon the voltage of the battery, and the resistance of the resistor, which in this case is 6-ohms. There will be a similar path from the negative terminal of the battery and through the second resistor and back to the positive terminal of the battery.

Since the two resistors are of equal value, for a given battery voltage, equal currents will flow through the two resistors. Let us suppose that the battery voltage is 6 volts. Then, the current flowing through either of the 6-ohm resistors will be 1 amp. This means that the total current flowing in the circuit will be 2 amps, 1 amp through each resistor.

Now, since we know the battery voltage and the total current flowing, we can substitute these values in Ohm's Law and find the effective resistance in the circuit. Using

$$R = \frac{E}{I}$$

$$R = \frac{6}{2} = 3 \text{ ohms}$$

Thus the resistance of two 6-ohm resistors connected in parallel is 3 ohms - notice that it is one half the resistance of either resistor.

You can set up other examples of equal resistors connected in parallel, and you will find that it always works out that the total resistance of the resistors in parallel is equal to one half the resistance of either resistor.

You might wonder about our selecting a voltage of 6 volts to work out this problem. We selected 6 volts simply to make the division easy. We could select any voltage; the current through each resistor would be different, but the result will always be the same. For example, suppose we select a battery voltage of 18 volts. Then, from Ohm's Law, the current through each resistor will be three amps, and therefore the total current flowing in the circuit will be 6 amps. When we substitute these values into Ohm's Law we find that once again the total resistance in the circuit is 3 ohms. Selecting a voltage like this is an easy way of finding the resistance of two resistors connected in parallel: there is another method that can be used which we will show you later.

You can use the same procedure in finding the total resistance of two unequal resistors connected in parallel. For example, suppose we have a 4-ohm resistor and an 8-ohm resistor connected in parallel as shown in Fig. 12A. We can simply set up a simple circuit such as shown in Fig. 12B and then assume a convenient battery voltage which

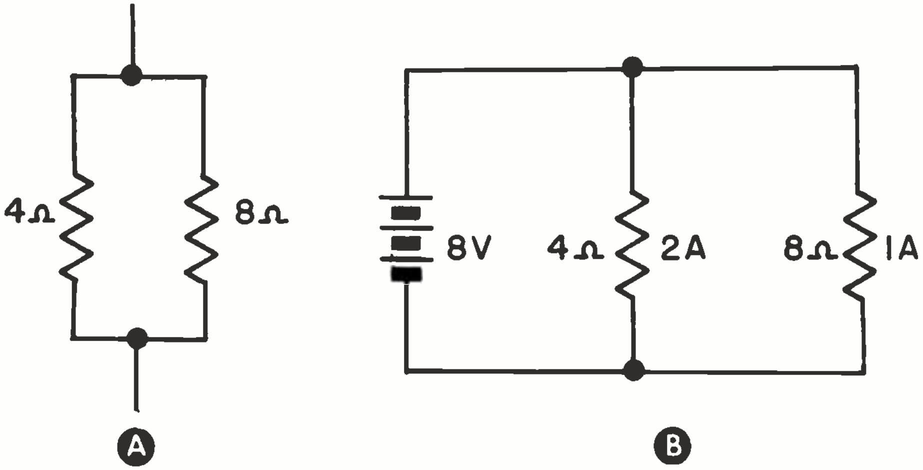

Fig. 12. Finding the value of 4Ω in parallel with 8Ω.

in this case might be 8 volts. With a voltage of 8 volts, a current of 2 amps will flow through the 4-ohm resistor and a current of 1 amp, will flow through the 8-ohm resistor. Therefore the total current flow in the circuit will be 3 amps. Now to find the total resistance we divide 3 amps into 8 volts and get 2.67 ohms.

In the examples shown in Figs. 11 and 12, it was easy to pick a voltage into which the resistance values can be divided to give convenient values of current. Sometimes this is not so easy and then we use another method of finding the value of resistors connected in parallel. We use the formula

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

This formula states that the total resistance of two resistors connected in parallel is equal to the product of the resistance of the two resistors divided by the sum of the resistance of the two resistors.

For example, using the two 6-ohm resistors that we used in Fig. 11, in this formula we get

$$R_t = \frac{6 \times 6}{6 + 6}$$

$$R_t = \frac{36}{12} = 3 \text{ ohms}$$

This formula is particularly useful in finding the value of larger resistors. For example, find the value of 2400 ohms in parallel with 800 ohms. Substituting these values in the formula we get

$$R_t = \frac{2400 \times 800}{2400 + 800}$$

$$R_t = \frac{1920000}{3200}$$

and now cancelling two zeros above the division line and two zeros below the division line, we have

$$R_t = \frac{19200}{32} = 600 \text{ ohms}$$

Often you will have more than two resistors connected in parallel and want to find the total resistance of the group. In Fig. 13A we have shown three resistors in parallel. In Fig. 13B we have shown them connected across a battery. If we assume a battery voltage of 24 volts, then we will get a whole number for the current flowing through each resistor. The current through the 6-ohm resistor would be 4 amps, the current through the 8-ohm resistor would be 3 amps, and the current through the 12-ohm resistor would be 2 amps. This will give us a total current of 9 amps. Now using Ohm's Law we can find the total resistance

$$R = \frac{E}{I}$$

$$R = \frac{24}{9} = 2.666+ \text{ ohms}$$

which we round off to 2.7 ohms.

Another way to find the total resistance of three resistors in parallel is to use the formula first for two of the group, finding the parallel resistance, and then using the formula again with the result and the third resistor in parallel with the parallel resistance of the first two resistors.

In the example, if we find the resistance of the 6-ohm and 12-ohm resistor in parallel first, we will have less work to do with fractions. Using the formula, we find that 6 ohms in parallel with 12 ohms is

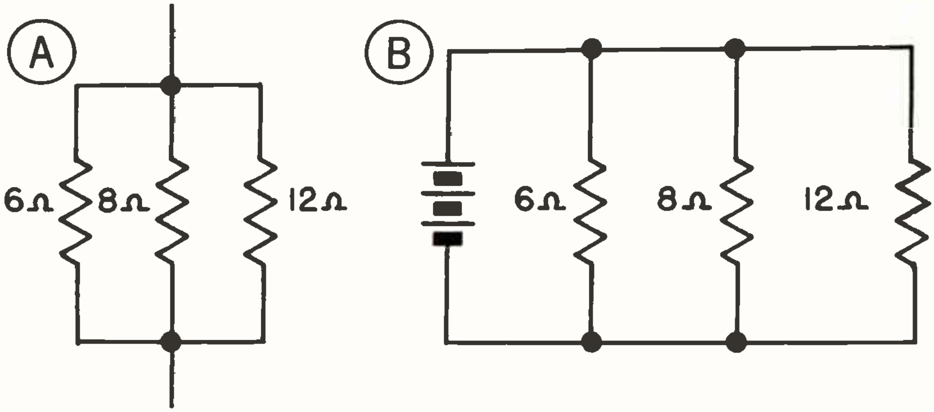

Fig. 13. A parallel circuit with three current paths.

$$R_t = \frac{6 \times 12}{6 + 12}$$

$$R_t = \frac{72}{18} = 4 \text{ ohms}$$

Thus the value of a 6-ohm resistor in parallel with a 12-ohm resistor is 4 ohms. Now we find the value of 4 ohms in parallel with 8 ohms, which we did previously and we find

$$R_t = \frac{4 \times 8}{4 + 8}$$

$$R_t = \frac{32}{12} = 2.666+ \text{ ohms}$$

Again we round it to 2.7 ohms.

If you have four or five resistors connected in parallel you can use the same formula, simply grouping them together in pairs and then substituting the parallel resistance in the formula. For example, in the case of five resistors you might find the value of R_1 and R_2 in parallel and then the value of R_3 and R_4 in parallel. Next, find the parallel resistance of the R_1-R_2 combination in parallel with the R_3-R_4 combination, and when you get the answer to the value of these four resistors in parallel, find the value of the four of them in parallel with R_5. When working out a problem of this type, sometimes it is worthwhile to look for groups that will work out in even numbers before starting the problem, and this will save some work. For example, look at the five resistors in parallel in Fig. 14.

In this example, if we group together R_1 and R_2 we get

$$R_t = \frac{12 \times 24}{12 + 24}$$

$$R_t = \frac{288}{36} = 8 \text{ ohms}$$

Therefore we can consider R_1 and R_2 as a single 8-ohm resistor. Now notice that the value of R_4 is 8 ohms, so let us consider the parallel combination of R_1 and R_2 which is equal to 8 ohms, with R_4. We can use the formula to find the value, but if we remember that the value of equal resistors in parallel is equal to one half the resistance of either resistor

ALSO! → $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots \frac{1}{R_N}$

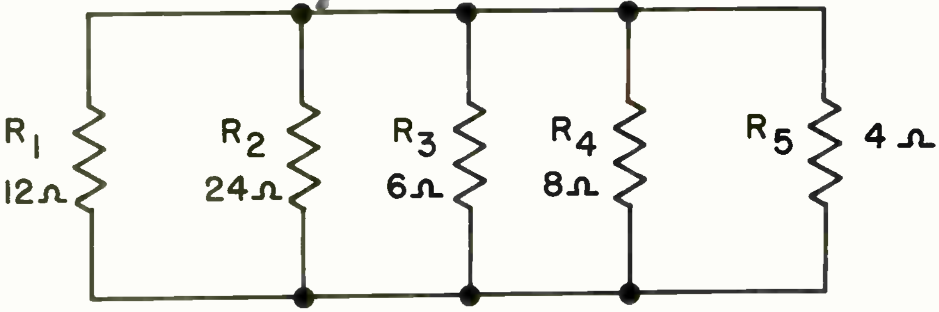

Fig. 14. Five resistors in parallel.

we know immediately that the parallel combination is equal to 4 ohms.

Now we consider the parallel combination of R_1, R_2 and R_4 as a single 4-ohm resistor. We now find the value of it in parallel with R_5, which is also a 4-ohm resistor, and we know immediately that the value of this combination is 2 ohms. Now we know that R_1, R_2, R_4 and R_5 in parallel have a resistance of 2 ohms. Now all we need to do is find the value of 2 ohms in parallel with R_3, which is 6 ohms, and we use the formula to do this.

$$R_t = \frac{6 \times 2}{6 + 2}$$

$$R_t = \frac{12}{8} = 1.5 \text{ ohms}$$

You can work this problem out by grouping other resistors together first; try working it out grouping R_1 and R_3 together first, get the value of this combination, and next get the value of R_2 and R_4 in parallel. After you have done this decide for yourself which two you should group together next to make your calculation as easy as possible, and then find the value of this combination in parallel with the remaining resistance to see if you get the same answer of 1.5 ohms.

Before leaving this section on resistors in parallel, there are a few other important points that you should notice.

Notice that in each of the examples given in Figs. 11, 12, 13 and 14 the total resistance of the resistors in parallel is less than the resistance of the smallest resistor. This is always true in a parallel circuit. Whenever you connect two or more resistors in parallel, the resistance of the parallel combination will always be less than the resistance of the smallest resistor, regardless of the value of the resistors connected in parallel.

If you look back at Fig. 11 you can see why this is so. You know from Ohm's Law that

$$R = \frac{E}{I}$$

Whenever you connect a resistor across a battery, a current flows in the circuit and for a given value of voltage a certain current will flow. If the voltage remains constant in the circuit and the current increases, then the resistance must get smaller. Whenever you connect a second resistor across a first resistor the current increases because there is a second path through which current can flow. Therefore when you connect two resistors in parallel and the value of E remains the same, the value of I increases and therefore the value of R must get smaller.

Sometimes when two resistors are connected in parallel, one resistor is so much larger than the other that practically all of the current flowing in the circuit flows through the smaller resistor. For example, if a 1000-ohm resistor is connected in parallel with a 1-ohm resistor and the two are connected across a battery, one thousand times as much current will flow through the 1-ohm resistor as through the 1000-ohm resistor. The current flowing through the 1000-ohm resistor would be such a small percentage of the total current flow in the circuit that it could be ignored. For all practical purposes, the total resistance of the two resistors in parallel can be considered as 1 ohm.

In most electronic circuits exact calculations are not necessary because most of the parts have a reasonable tolerance. If we want to get an approximate value of a group of resistors connected in parallel, we can usually ignore any resistor that is more than ten times larger than the smallest resistor in the circuit. Thus, if you had a 2-ohm, a 4-ohm and a 50-ohm resistor connected in parallel and wanted to get the approximate resistance of the parallel combination, you could ignore the 50-ohm resistor because it is more than ten times the resistance of the 2-ohm resistor. The value of the resistance you would obtain by ignoring this resistor would not differ appreciably from the value you would obtain if you did not ignore it and found the exact resistance of the parallel combination. Keep this in mind, because sometimes it will save you some unnecessary work if you are interested in finding only the approximate resistance of a group of resistors in parallel and do not need to know the exact resistance.

VOLTAGE AND CURRENT IN PARALLEL CIRCUITS

In a series circuit, the current is the same in all parts of the circuit. The voltage drop across a part in a series circuit depends upon the resistance of the part.

In a parallel circuit we have essentially the opposite situation. In a parallel circuit, since the parts are connected directly across each other, the voltage across each part must be the same. This means that the voltage across all the parts in a parallel circuit is the same. You cannot have two parts connected in parallel and have unequal voltages across them.

The current that will flow through each part in a parallel circuit will depend upon the voltage applied across the parallel circuit and the resistance of the part. Since each branch of a parallel circuit can have a different resistance, then we can have a different current flowing in each branch of the circuit.

Therefore, you should remember that in a parallel circuit the voltage will be the same across each part in the circuit. The current through each branch of the circuit will depend on the resistance of the branch. The highest current will flow through the branch having the lowest resistance and the lowest current will flow through the branch having the highest resistance. The total current flowing in a parallel circuit is equal to the sum of the currents flowing through the individual branches.

SUMMARY

Parallel circuits are widely used in electronic equipment and you will see many examples of them later in your course.

There are several important things you should remember about resistors in parallel. Remember that when two or more resistors are connected in parallel the total resistance of the parallel combination will always be less than the resistance of the smallest resistor.

When two equal value resistors are connected in parallel, the total resistance will be equal to one half the resistance of either resistor. If three equal value resistors are connected in parallel, the total resistance will be one third the resistance of either resistor, and if four equal value resistors are connected in parallel, the total resistance will be one quarter the resistance of any one resistor.

We can find the resistance of two resistors connected in parallel by using the formula

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

In a parallel circuit the voltage across all branches of the parallel circuit will be equal. The current flow in each branch of the circuit will depend upon the resistance of the circuit, the highest current will flow through the lowest resistance branch, and the lowest current will flow through the highest resistance branch.

Now answer the self-test questions on this section of the lesson; they will be a good review for you.

SELF-TEST QUESTIONS

(l) What is the total resistance of two 50-ohm resistors connected in parallel?

(m) What is the total resistance of a 24-ohm resistor connected in parallel with a 12-ohm resistor?

(n) If a 3-ohm and a 4-ohm resistor are connected in parallel across a 12-volt battery, what will be the total current flow from the battery, and what will be the total resistance of the 3-ohm and 4-ohm resistance in parallel?

(o) If two 8-ohm resistors are connected in parallel with a 1000-ohm resistor, what will be the resistance of the parallel combination?

(p) If two resistors, R_1 and R_2, are connected in parallel across a battery and a current of 1 amp flows through R_1 and a current of 2 amps flows through R_2, which is the larger resistor? How much larger is it than the other resistor?

(q) If a 5-ohm resistor and a 10-ohm resistor are connected in parallel across a battery, and the current through the 5-ohm resistor is 2 amps, find the voltage across the 10-ohm resistor and the current that will flow through it. What is the total current flowing in the circuit? What is the battery voltage?

(r) Complete the following statement: in a parallel circuit, the voltages across all branches of the parallel circuit will be __________.

(s) In a parallel circuit, the current through each branch of a parallel circuit will depend upon ______________ of the branch. The largest current will flow through the branch having the ______ resistance, and the smallest current will flow through the branch having the __________ resistance.

Series-Parallel Circuits

In radio and television transmitters and receivers as well as in all types of electronic control devices you will find many series circuits and many parallel circuits. However, in addition to these two types of circuits you will find many circuits that are combinations of series and parallel circuits. These types of circuits are called series-parallel circuits.

An example of a series-parallel circuit is shown in Fig. 15. In this circuit, the two resistors, R_2 and R_3, are connected in parallel. Any current flowing in the circuit, when it reaches the junction of R_2 and R_3 has two paths through which it can flow. Part of the current can flow through R_2 and part of it can flow through R_3. The exact percentage of the current that will flow through each resistor will depend upon their relative size. If the resistors are equal, half the current will flow through R_2 and half of it will flow through R_3. On the other hand, if one of the resistors is much larger than the other, most of the current will flow through the smaller resistor and only a small percentage of the current will flow through the larger resistor.

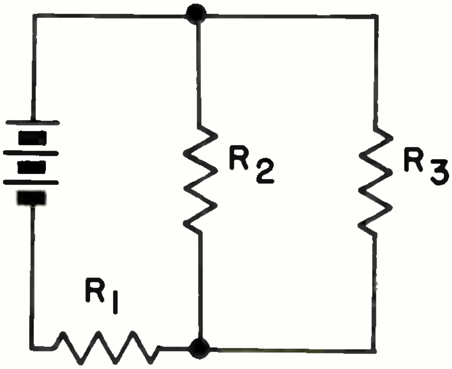

Fig. 15. A series-parallel circuit.

The two parallel resistors R_2 and R_3 are connected in series with the resistor R_1 and with the battery. Thus, part of the circuit is a simple series circuit and part of it is a parallel circuit.

In a circuit of this type, electrons leave the negative terminal of the battery and flow through the resistor R_1. The current divides after it flows through R_1, and part flows through R_2 and part flows through R_3. Then the current joins at the junction of the two resistors and flows back to the positive terminal of the battery and through the battery back to the negative terminal.

In solving for values of current, voltage and resistance in a series-parallel circuit, we use the rules

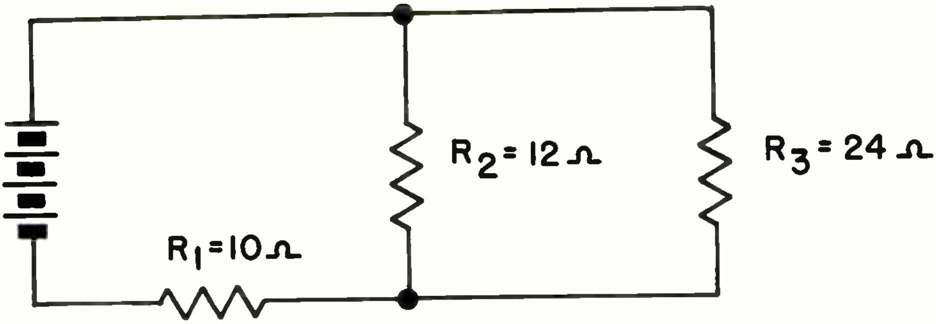

Fig. 16. A series-parallel circuit.

that apply to a series circuit for the series part of the circuit, and the rules that apply to a parallel circuit for the parallel part of the circuit. Actually, it is no more difficult to work with this type of circuit and find voltages, current etc., than it is with a simple series or a simple parallel circuit. However, there is a certain order in which you must proceed when working with circuits of this type. Once you become familiar with this type of circuit, you will see that it is not as complicated as it might look, and also learning about series-parallel circuits will make simple series and simple parallel circuits that much easier for you.

Now let us go ahead and study this type of circuit in detail.

RESISTANCE IN SERIES-PARALLEL CIRCUITS

In Fig. 16 we have shown a series-parallel circuit similar to the one shown in Fig. 15. In this example, R_1, which is called a series resistor, is equal to 10 ohms. R_2 and R_3 are called the parallel resistors. R_2 has a resistance of 12 ohms and R_3 has a resistance of 24 ohms. Now, we want to find the total resistance in the circuit. In other words, we want to find out how much resistance there is in the circuit limiting the current flow from the battery.

To find the total resistance of a series-parallel circuit of this type, the first step is to find the resistance of the parallel branch. To do this, we use the formula

$$R_p = \frac{R_2 \times R_3}{R_2 + R_3}$$

and we substitute the values of 12 ohms for R_2 and 24 ohms for R_3 and get

$$R_p = \frac{12 \times 24}{12 + 24}$$

$$R_p = \frac{288}{36} = 8 \text{ ohms}$$

Now, we know that the total resistance of R_2 in parallel with R_3 is 8 ohms. Insofar as the circuit is concerned, these two resistors could be replaced by a single 8-ohm resistor, as shown in Fig. 17. Notice the symbol we have used to indicate R_2 in parallel with R_3. The two parallel lines between R_2 and R_3 mean "in parallel with".

Once we replace the parallel combination of R_2 and R_3 with the equivalent resistance, we have a simple series circuit. As you will remember, the total resistance of a series circuit is equal to the sum of the individual resistances. In this case, the total resistance will be 10 + 8 = 18 ohms. This is the total resistance of the equivalent circuit shown in Fig. 17, and it is also the total resistance seen by the battery in the series-parallel circuit shown in Fig. 16.

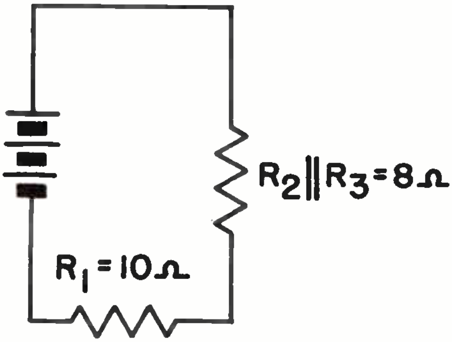

Fig. 17. Series equivalent of circuit of Fig. 15.

So far the circuits we have been dealing with have been very simple series-parallel circuits. In some circuits we will have several series resistors and several parallel branches. The parallel branches may consist of any number of resistors. A more complicated series-parallel circuit is shown in Fig. 18. To find the total resistance seen by the battery in this circuit, we will use exactly the same method as we used to find the total resistance in the circuit shown in Fig. 16. The first thing we will do is find the effective resistance of the parallel branches and then redraw the circuit replacing the parallel branches by single series resistors and then find the total series resistance. Now let us go through this problem step by step.

Notice that in the circuit shown in Fig. 18 we have two series resistors, R_1 and R_5. We also have two parallel branches. One parallel branch is made up of the three resistors R_2, R_3 and R_4, and the other

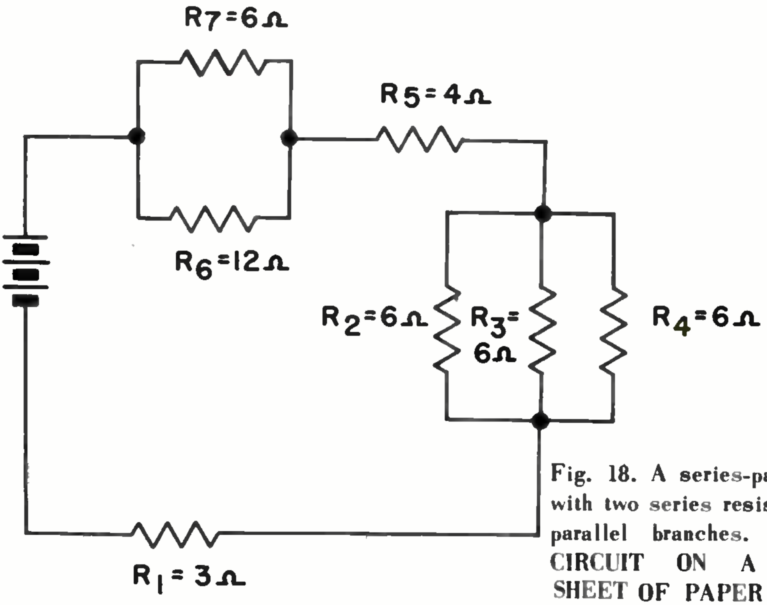

Fig. 18. A series-parallel circuit with two series resistors and two parallel branches. COPY THIS CIRCUIT ON A SEPARATE SHEET OF PAPER FOR QUICK REFERENCE.

parallel branch is made up of the two resistors R_6 and R_7.

Our first step in solving this problem is to find the resistance of the parallel branches. Let us take the branch made up of the three resistors first. If you will remember from the preceding section, we mentioned that when two equal value resistors are connected in parallel, the total resistance is equal to one half the resistance of either resistor. When three equal value resistors are connected in parallel the total resistance is one third the value of one of the resistors. From this we know immediately that the total resistance of the three six-ohm resistors in parallel is 2 ohms.

However, you might not remember this rule, or the resistors might not be of equal values. In this case you simply use the formula and find the resistance of two of the resistors in parallel. This would give you

$$R = \frac{6 \times 6}{6 + 6}$$

$$R = \frac{36}{12} = 3 \text{ ohms}$$

Now this gives you the value of two of the resistors in parallel and you combine this value with the remaining resistor to get the total resistance of the combination. Thus

$$R_t = \frac{3 \times 6}{3 + 6}$$

$$R_t = \frac{18}{9} = 2 \text{ ohms}$$

Therefore the resistance of the parallel branch made up of the three 6-ohm resistors is 2 ohms. As far as the circuit is concerned, we can replace these three resistors by a single 2-ohm resistor.

Now let us go ahead and find the value of the 12-ohm and 6-ohm resistors in parallel. Again, using our formula we get

$$R_t = \frac{12 \times 6}{12 + 6}$$

$$R_t = \frac{72}{18} = 4 \text{ ohms}$$

Therefore R_6 and R_7 can be replaced by a single 4-ohm resistor without affecting the total resistance of the circuit.

Now we can redraw the circuit shown in Fig. 18 as we have redrawn it in Fig. 19. In place of the three parallel resistors we have inserted a single 2-ohm resistor, and in place of resistors R_6 and R_7 we have inserted a 4-ohm resistor. Now we have a simple series circuit, and to get the total resistance of the circuit we simply add the resistance of the individual resistors. Therefore the total resistance in the circuit is

$$R_t = 3 + 2 + 4 + 4 = 13 \text{ ohms}$$

This same procedure can be used for solving any series-parallel circuit configuration. In fact, the circuit shown in Fig. 18 could consist of four parallel branches in series. There could be a resistor in parallel with R_1 and another resistor in parallel with R_5. In this case you would have a series circuit made

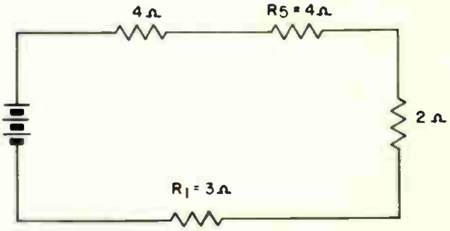

Fig. 19. Series equivalent of circuit of Fig. 18.

up of four parallel branches connected in series. To solve a circuit of this type you use the same procedure. Find the total resistance of each parallel branch, and then draw the equivalent circuit as we did in Fig. 19 and then total the resistance of the parallel branches to get the total resistance in the circuit.

Now let us see how the current behaves in a series-parallel circuit.

CURRENT IN SERIES-PARALLEL CIRCUITS

In a series-parallel circuit such as shown in Fig. 18, the current must be the same in every series part of the circuit. By this we mean that a certain current leaves the negative terminal of the battery and flows through R_1. Then the current reaches the parallel combination of R_2, R_3 and R_4. The total current flowing through this parallel combination must be equal to the current leaving the negative terminal of the battery and the current flowing through R_1. The same current must flow through R_5 and the same current must flow through the parallel combination of R_6 and R_7.

To help us see better what is happening to the current in the circuit, let's assume that the battery voltage in Fig. 18 is 78 volts. We picked this value because it will enable us to avoid any decimal divisions.

We have already found that the total resistance of the circuit - that is, the resistance that the battery sees - is 13 ohms. Therefore, we can use this to find the current that will flow in the circuit. Using the formula

$$I = \frac{E}{R}$$

and substituting 78 volts for E and 13 ohms for R we have

$$I = \frac{78}{13} = 6 \text{ amps}$$

This means that the current leaving the negative terminal of the battery is 6 amps. Since R_1 is in series with the battery, the current flowing through R_1 must also be 6 amps. The current flowing through the parallel combination of R_2, R_3 and R_4 must also be 6 amps. However, there are three paths here through which the current can flow. Since the three resistors are of equal value, then one third of the current will flow through each branch. This means that 2 amps will flow through R_2, 2 amps through R_3 and 2 amps through R_4.

The current reaching R_5 must flow through this resistor and since the series current is 6 amps, the current flow through R_5 must be 6 amps.

R_6 and R_7 form a parallel branch. Part of the current will flow through R_6 and part of it will flow through R_7. Since R_6 is twice the value of R_7, then the current flow through R_6 will be only half the current flowing through R_7. This means that one third of the current will flow through R_6 and two thirds of it will flow through R_7. Therefore the current flow through R_6 will be 2 amps, and the current flow through R_7 will be 4 amps. The current flowing into the positive terminal of the battery will be 6 amps, and the current flow through the battery itself from the positive terminal to the negative terminal will also be 6 amps.

Now notice how this circuit has

obeyed the laws set down both for series circuits and for parallel circuits. We stated that in a series circuit, the current is the same in all parts of the circuit. R_1 is a part of the series circuit and the current through it is 6 amps. R_2, R_3 and R_4 in parallel form a part of the series circuit and the current through the three in parallel is 6 amps. The current divides because there are three paths, but the total current flowing through the three paths is 6 amps. R_5 does not have any other resistors in parallel with it and therefore the entire current of 6 amps flows through it. R_6 and R_7 in parallel form a part of the series circuit and the total current flowing through the two of them is 6 amps; part of it flows through R_6 and part of it through R_7. The entire 6 amps also flows through the battery. Thus we can say that the current flow in each part of this series circuit is 6 amps.

The current flow also obeys the law of parallel circuits. Whenever the current reaches a parallel branch it divides, and part of it flows through each branch of the circuit. Since R_2, R_3 and R_4 are of equal value, the same current flows through each of the three resistors. In this case, 2 amps flow through each resistor so that the total current flowing in this part of the series circuit is 6 amps. In the case of R_6 and R_7 in parallel, the current again divides and flows through the two resistors in proportion to their resistance. R_6 is twice the resistance of R_7 and therefore only half as much current flows through R_6 as R_7. 2 amps flow through R_6 and 4 amps through R_7. This gives us a total current of 6 amps, once again through this part of the series circuit.

Now that we have looked into resistance and current in series-parallel circuits, let us see what happens to the voltage in these circuits.

VOLTAGE IN SERIES-PARALLEL CIRCUITS

You will remember that in a series circuit, the sum of the voltage drops across the branches of the series circuit is equal to the applied voltage. You will also remember, that in a parallel circuit you have the same voltage across all the parts in parallel. Now let us see what happens in a series-parallel circuit. Let's use the circuit in Fig. 18 so we don't have to figure out the total resistance again, and once again let's assume that the battery voltage is 78 volts. We know that this will cause a current of 6 amps to flow in the circuit.

With a current of 6 amps flowing through R_1, we can find the voltage drop across it. We will refer to this voltage as E_1, the voltage across R_2 as E_2 and so on.

$$E_1 = 6 \times 3 = 18 \text{ volts}$$

We know that the current flowing through R_2 is 2 amps, and using this we can find the voltage across R_2.

$$E_2 = 2 \times 6 = 12 \text{ volts}$$

Since $R_2 = R_3 = R_4$, and the current flowing through each of these resistors is 2 amps, they must have the same voltage drop across each of the resistors. This bears out what we have said before about parts connected in parallel - the voltage drop across them must be the same.

If we stop here and look at Fig. 19, we see that we found the equivalent resistance of R_2, R_3 and R_4 connected in parallel was 2 ohms. In this circuit, the current flowing through this equivalent resistance is 6 amps, and the voltage across it will be 12 volts. Therefore we see that no matter which way we work, either using the total current across the equivalent resistance or the actual current through one branch of the parallel circuit, we should get the same value of voltage across the parallel circuit.

The voltage across R_5 will be

$$E_5 = 6 \times 4 = 24 \text{ volts}$$

The voltage across R_6 will be

$$E_6 = 2 \times 12 = 24 \text{ volts}$$

We know that the current through R_7 is 4 amps and so we can also calculate the voltage across this resistor to see that we have the same voltage as across R_6. The voltage across R_7 is

$$E_7 = 4 \times 6 = 24 \text{ volts}$$

Now, let us add the voltage drops around the circuit to see what the total voltage drop is. The voltage drop across R_1 is 18 volts. The voltage drop across the parallel combination of R_2, R_3 and R_4 is 12 volts. The voltage drop across R_5 is 24 volts and the voltage drop across the parallel combination of R_6 and R_7 is also 24 volts. Now adding these voltages we will get the total voltage drop in the circuit

$$E_t = 18 + 12 + 24 + 24 = 78 \text{ volts}$$

The series-parallel circuit thus obeys the law we stated for the voltage drops in a series circuit. The sum of the voltage drops across each of the series branches in a series-parallel circuit is equal to the source voltage. The voltage drop across each of the parts in a parallel branch is equal. Thus we can see that the rules we have set up for voltages in series and in parallel circuits apply also to series-parallel circuits.

Now, if you plan to become a radio-TV service technician, this is as far as you have to go with series-parallel circuits. However, if you want to go ahead and get your FCC license, or if you plan on working in industry, you should be able to solve some simple problems in series-parallel circuits. You will have to solve these problems to get your FCC license. Often when applying for positions in industry, examinations are given and frequently these examinations have one or two problems involving solutions of parallel series and series-parallel circuits. For the technician who wants to get his FCC license or wants to work in industry, and for the radio-TV service technician who wants to learn more about series-parallel circuits we will go through a typical problem in the next section. Remember, if your interest is radio-TV servicing only, you do not have to go through this section unless you want to.

PROBLEMS IN SERIES-PARALLEL CIRCUITS

In Fig. 20 we have shown a series-parallel circuit that is only slightly more complicated than the one shown in Fig. 18. In this circuit you are given the values of all the resistors

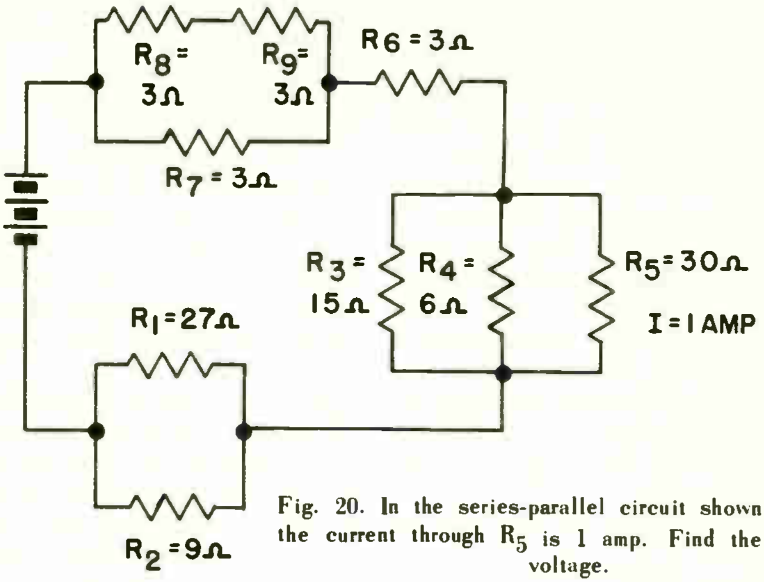

Fig. 20. In the series-parallel circuit shown above, the current through R_5 is 1 amp. Find the source voltage.

and also the information that the current flowing through R_5 is 1 amp. The problem is to find the source voltage.

At first glance, you might think that this is impossible, but actually it is not nearly as difficult as it might appear at first. Let us look at the information we have about R_5.

We know that the resistance of R_5 is 30 ohms, and that the current flowing through it is 1 amp. From this we can calculate the voltage across R_5 using Ohm's Law. We use the formula

$$E = IR$$

and for I substitute 1 amp and for R, 30 ohms, and we will get

$$E = 1 \times 30 = 30 \text{ volts}$$

Since R_3 and R_4 are in parallel with R_5, this means that the voltage across R_3 and the voltage across R_4 is also 30 volts. Now that we know the voltage across these two resistors, and their value, we can find the current flowing through them. We will use I_3 for the current through R_3 and I_4 for the current through R_4 and so on throughout the problem.

$$I_3 = \frac{30}{15} = 2 \text{ amps}$$

$$I_4 = \frac{30}{6} = 5 \text{ amps}$$

Now we know that the current flowing through R_3 is 2 amps, through R_4 is 5 amps, and the current flowing through R_5 is 1 amp. Thus the total current flowing through the three parallel branches is

$$I_t = 2 + 5 + 1 = 8 \text{ amps}$$

Since this combination of three resistors forms one branch in series circuit, now we know that the series current must be 8 amps. We can immediately calculate the voltage drop across R_8 using this information.

$$E_8 = 8 \times 3 = 24 \text{ volts}$$

Now we know that the voltage drop across R_8 is 24 volts and the voltage drop across the parallel combination of the three resistors is 30 volts. We know that the source voltage will be equal to the sum of the voltage drops around the series circuit so if we can find the voltage drop across the parallel combination of R_1 and R_2 and also the voltage drop across the parallel combination of R_7 in parallel with R_8 and R_9, we'll be able to find the sum of the voltage drops and hence the source voltage.

We can find the voltage drop across the parallel combination of R_1 and R_2 quite easily. Notice that R_1 is three times as large as R_2. This means that the current flowing through R_2 will be three times the current flow through R_1. In other words, if the current flow through R_1 is 1 amp, then the current flow through R_2 would be 3 amps which would give us a total of 4 amps flowing through the two resistors. However, we know that the total current flow in the circuit is 8 amps, therefore the current flowing through R_2 must be 6 amps and the current flowing through R_1 must be 2 amps.

Sometimes you can't divide the current flow this easily, but we can still find what the voltage drop across the two resistors must be by finding the resistance of the parallel combination. To do this, we substitute the values of R_1 and R_2 in our parallel formula

$$R = \frac{27 \times 9}{27 + 9}$$

$$R = \frac{243}{36} = 6.75 \text{ ohms}$$

Now we know that the resistance of R_1 and R_2 in parallel is 6.75 ohms and that the current flowing through the parallel combination is 8 amps; we can find the voltage drop across this combination.

$$E = 8 \times 6.75 = 54 \text{ volts}$$

If you noticed that the current flow through R_2 must be 6 amps and the current flow through R_1 must be 2 amps, then you can use either current flow along with the appropriate resistor to get the voltage drop across the parallel combination.

$$E_1 = 2 \times 27 = 54 \text{ volts}$$

and if you use R_2 in the current flow through it, you would get

$$E_2 = 6 \times 9 = 54 \text{ volts}$$

Notice that no matter how you work it out, either finding the total equivalent resistance and using the total current, or using the resistance of either branch and the current flow through it, you always get the same voltage drop across the parallel combination or R_1 and R_2.

Now all we need to do is find the equivalent resistance of R_7 in parallel with R_8 and R_9, and we can find the voltage drop across this combination. The first step is to find the resistance of R_8 in series with R_9. This is simply 3 + 3 = 6 ohms. Now we have a total of 6 ohms in parallel with 3 ohms; we want to find the resistance of this parallel combination. Again, we use our formula for parallel resistors and get

$$R = \frac{3 \times 6}{3 + 6}$$

$$R = \frac{18}{9} = 2 \text{ ohms}$$

Since the parallel combination of R_7 in parallel with R_8 and R_9 has a resistance of 2 ohms, and the current flowing through this combination is 8 amps, we can find the voltage drop across the parallel combination

$$E = 8 \times 2 = 16 \text{ volts}$$

Now we have the voltage drop across each branch in the series-parallel circuit and all we need to do is add these voltage drops - they must be equal to the source voltage. Therefore the total voltage is equal to

$$E_t = 54 + 30 + 24 + 16 = 124 \text{ volts}$$

This is typical of the problems involving the series-parallel circuits that you might have to work out either on an FCC examination or on an examination for employment in industry. Notice that the problem is not difficult; you just start using Ohm's Law in a part of the circuit where you have two of the three quantities, E, I or R, and then find the third. You use this information to learn more about the circuit and work one step at a time. In the circuit shown in Fig. 20 we were able to determine the current flowing in each part of the circuit, the voltage drop in each branch of the circuit, and the total voltage applied to the circuit. If we wanted to, we could also add the resistance of the individual branches of the circuit and find the total resistance of the circuit; or, since we know the total voltage in the circuit we could simply divide this by the current to get the total resistance in the circuit. Solving problems of this type are really not any more difficult than solving simple Ohm's Law problems; they are simply longer because there are more steps involved.

SUMMARY

Series-parallel circuits are important because you will run into them in all types of electronic equipment. In a series-parallel circuit you will have a voltage source in series with a combination of series and parallel components. You may have one series branch and one parallel branch or you may have several of each. In the parallel branches there may be any number of components.

In a series-parallel circuit the total current flow is the same in all series branches of the circuit. In the parallel branches, the sum of the currents in the individual branches must be equal to the series current flow. The voltage drop across all the components in the parallel branch is the same and the voltage drop across the series components will depend upon the resistance of the component and the total current flowing in the circuit.

To find the total resistance in a series-parallel circuit, you reduce the parallel branches to the equivalent series resistance, and then add the series branches with the equivalent resistance of the parallel branches. The total current flow in the circuit can be determined from the source voltage divided by the total resistance of the circuit and the voltage drop across individual parts in the circuit can be found by using Ohm's Law.

Solving problems involving series-parallel circuits is simply a matter of taking one step at a time, making simple applications of Ohm's Law until the entire circuit is solved.

The following self-test questions are designed to help you with series-parallel circuits. If you find that you are having difficulty with one of the problems, be sure to go back and review. Try to work the problem through on your own, but if you find you can't, look for help at the back of the book - the solutions to the problems are given there. If you have to go to the back of the book to try to find out how to do a problem, make sure you understand that problem before tackling the next one; the chances are that if you will do this, then you will be able to work the next problem by yourself.

SELF-TEST QUESTIONS

(t) Draw a series-parallel circuit containing a battery and three resistors in which R_1 and R_2 are in parallel and connected to the negative terminal of the battery, and R_3 is a series resistor and connected to the positive terminal of the battery.

(u) If $R_1 = 20$ ohms and $R_2 = 30$ ohms, and $R_3 = 12$ ohms, find the total resistance in the circuit.

(v) Using the values of R_1, R_2 and R_3 for the preceding problem, if the battery voltage is 48 volts, find the voltage drop across each resistor in the circuit, and the current flow through each resistor.

(w) If in a circuit like the one shown in Fig. 15, $R_1 = 5$ ohms, $R_2 = 10$ ohms and $R_3 = 10$ ohms, what is the source voltage if the current through R_2 is 1 amp.

(x) Find the total resistance in a series-parallel circuit like the one shown in Fig. 18 when $R_1 = 5$ ohms, R_2, R_3 and R_4 are each equal to 12 ohms, $R_5 = 6$ ohms, $R_6 = 48$ ohms and $R_7 = 24$ ohms.

(y) Complete the following statement: In a series-parallel circuit, the current is the ______ in each series branch of the circuit.

(z) Complete the following statement: In a parallel branch of a series-parallel circuit, the sum of the currents through the branches of the parallel circuit is ______ to the total current flowing in the series part of the circuit.

ANSWERS TO SELF-TEST QUESTIONS

(a) A series circuit is a circuit in which the voltage source and the parts are connected, so that current leaving the negative terminal of the voltage source flows through first one part and then another to the positive terminal of the voltage source and then through the source back to the negative terminal.

(b) To measure the voltage of a battery with a dc voltmeter, you connect the negative terminal of the voltmeter to the negative terminal of the battery, and the positive terminal of the voltmeter to the positive terminal of the battery.

(c) See Fig. 1 and Fig. 3. Either figure is correct; they are the same circuit except in Fig. 3 the resistor values are given.

(d) The polarity of the voltage drops across the resistors is indicated in Fig. 8.

(e) The total resistance in the circuit will be equal to the resistance of the sum of the resistors. Therefore

$$R_t = 3 + 4 + 5 = 12 \text{ ohms}$$

(f) To find the voltage across any one of the resistors you simply use Ohm's Law. You know that

$$E = IR$$

You know the value of each of the resistors and the current will be the same through all resistors so you can find the voltage drop across each one.

$$E_{r1} = 2 \times 3 = 6 \text{ volts}$$

$$E_{r2} = 2 \times 4 = 8 \text{ volts}$$

$$E_{r3} = 2 \times 5 = 10 \text{ volts}$$

(g) You can find the source voltage in two ways. You can add the individual voltage drops you obtained in the preceding section and you will find that the source voltage is

$$6 + 8 + 10 = 24 \text{ volts}$$

You can also get the source voltage from the current times the total resistance, which you found to be 12 ohms. Using this you get

$$E = 2 \times 12 = 24 \text{ volts}$$

(h) You know that the sum of the voltage drops in a series circuit is equal to the source voltage. In this example, the source voltage is 35 volts. The voltage drops across the three resistors are 5 volts, 7 volts and 10 volts. Adding these three voltage drops, we get 22 volts. Therefore the voltage drop across the remaining resistor must be 13 volts.

(i) This problem is exactly the same as the preceding problem. In a series circuit, the sum of the voltage drops is equal to the source voltage. The source voltage is 250 volts, and therefore the voltage drops in the series circuit must add up to 250 volts. The voltage drop across R_1 is 3 volts, and the voltage drop across R_2 is 125 volts. Therefore the sum of the voltage drops across R_1 and R_2 is 128 volts. The remainder of the 250 volts must be dropped between the plate and cathode of the vacuum tube. Therefore the voltage drop across the tube must be 122 volts.

(j) This problem is the same as the preceding problem. The voltage drop across R_1 plus the voltage drop across R_2 is equal to 3.8 volts. Since the battery voltage is 6 volts, the difference, which is 2.2 volts, must be the voltage dropped between the emitter and the collector of the transistor.

(k) This problem is a review of just about everything you have learned about series circuits. To find the total resistance in a series circuit you add the resistance of the individual resistors. Therefore

$$R_t = 120 + 150 + 180 + 120 + 330 = 900 \text{ ohms.}$$

To find the current flowing in the circuit you use Ohm's Law in the form

$$I = \frac{E}{R}$$

Substituting 18 volts for E and 900 ohms for R we get

$$I = \frac{18}{900}$$

This will involve a decimal division and so we multiply it by 1000 and get our current directly in milliamperes. Thus our problem becomes

$$I = \frac{18}{900} \times 1000$$

$$I = \frac{18000}{900}$$

Now we cancel two zeros above and below the line and then we have

$$I = \frac{180}{9} = 20 \text{ ma}$$

To find the voltage drop across each of the resistors we use the formula

$$E = IR$$

We will refer to the voltage drop across R_1 as E_1 and the voltage drop across R_2 as E_2 and so on.

$$E_1 = \frac{20}{1000} \times 120$$

Notice that we wrote the current as

$$\frac{20}{1000}$$

The current must be in amperes and we convert 20 milliamperes to amperes by dividing it by 1000. Now continuing with the problem,

$$E_1 = \frac{20 \times 120}{1000}$$

$$E_1 = \frac{2400}{1000}$$

$$E_1 = \frac{24}{10} = 2.4 \text{ volts}$$

$$E_2 = \frac{20}{1000} \times 150$$

$$E_2 = \frac{3000}{1000} = 3 \text{ volts}$$

$$E_3 = \frac{20}{1000} \times 180$$

$$E_3 = \frac{3600}{1000}$$

$$E_3 = \frac{36}{10} = 3.6 \text{ volts}$$

$$E_4 = E_1 = 2.4 \text{ volts}$$

$$E_5 = \frac{20}{1000} \times 330$$

$$E_5 = \frac{6600}{1000}$$

$$E_5 = \frac{66}{10} = 6.6 \text{ volts}$$

Notice that we did not calculate the voltage across R_4. R_4 is equal to R_1 and since in a series circuit the same current flows through the entire circuit then the voltage drop across R_4 must be equal to the voltage drop across R_1. Therefore calculating the voltage a second time would simply be a waste of time. As a matter of fact, sometimes in a problem of this type you can save yourself some work by looking up the resistor values. For, example, if one resistor happened to be twice that of the other, you would know immediately that the voltage drop across it was twice as high as the voltage drop across the first resistor. Similarly if one resistor was three times another you could expect three times as high a voltage drop across it.

(l) 25 ohms. The total resistance of two equal resistors connected in parallel is always one half the resistance of either resistor.

(m) 8 ohms. You find the resistance of the two resistors in parallel by using the formula

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

and substituting 24 ohms and 12 ohms for R_1 and R_2 you get

$$R_t = \frac{24 \times 12}{24 + 12}$$

$$= \frac{288}{36} = 8 \text{ ohms}$$

(n) The current flow through each resistor can be found from Ohm Law's

$$I = \frac{E}{R}$$

The current through the 3-ohm resistor will be

$$I = \frac{12}{3} = 4 \text{ amps}$$

and the current through the 4-ohm resistor will be

$$I = \frac{12}{4} = 3 \text{ amps}$$

The total current flow will be the sum of these two currents or 7 amps. You can use this value of current and the voltage of 12 volts to find the resistance of the two resistors in parallel,

$$R = \frac{E}{I}$$

$$R = \frac{12}{7} = 1.7 \text{ ohms}$$

(o) 4 ohms. The resistance of two 8-ohm resistors in parallel will be 4 ohms, one half the resistance of either resistor. The 1000-ohm resistor is so large that we can simply ignore it because it will not affect the total resistance of the circuit appreciably. As a matter of fact, if you did consider it and calculated the value of the three in parallel you would find that the resistance worked out to be over 3.98 ohms. This is less than two parts in four hundred, an error which is so small it is insignificant, and it can be ignored.

(p) R_1 is the larger resistor because the smaller current flows through it. Since only half as much current flows through R_1 as through R_2, then R_1 must be twice the size of R_2.

(q) If the current through the 5-ohm resistor is 2 amps, then the voltage across it must be 10 volts. We use Ohm Law's in the form E = IR to determine this voltage. Since the two resistors are in parallel and connected across a battery we know that the battery voltage must be 10 volts, and the voltage across the 10-ohm resistor must be 10 volts. With 10 volts across the 10-ohm resistor, a current of 1 amp will flow through it. We would also know that a current of 1 amp must flow through the 10-ohm resistor since it is twice the size of the 5-ohm resistor, and therefore half the current would flow through it that flows through the 5-ohm resistor. The total current flowing in the circuit must be the sum of the current through the two resistors or 3 amps.

(r) In a parallel circuit, the voltage across all branches of the parallel circuit will be equal.

(s) In a parallel circuit, the current through each branch of a parallel circuit will depend upon the resistance of the branch. The largest current will flow through the branch having the lowest resistance, and the smallest current will flow through the branch having the highest resistance.

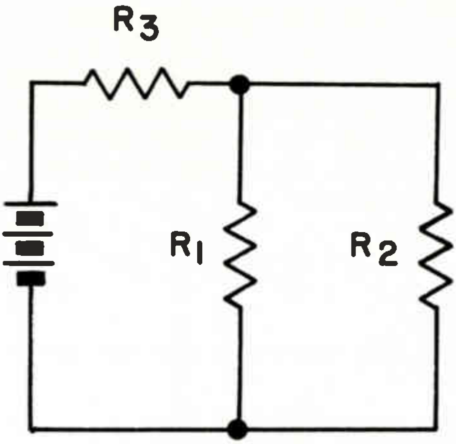

Fig. 21. Answer to Self-Test Question (t).

(t) See Fig. 21.

(u) 24 ohms. The total resistance of the parallel combination of R_1 and R_2 can be found from the parallel resistor formula. Substituting these values we get

$$R_t = \frac{20 \times 30}{20 + 30}$$

$$= \frac{600}{50} = 12 \text{ ohms}$$

This resistance is in series with R_3, which also has a resistance of 12 ohms, so the total resistance in the circuit is 24 ohms.

(v) With a voltage of 48 volts and a total resistance of 24 ohms, the total current flowing in the circuit will be

$$I = \frac{48}{24} = 2 \text{ amps}$$

This means that the voltage drop across R_3 will be

$$E = 2 \times 12 = 24 \text{ volts}$$

Therefore the voltage drop across the parallel combination of R_1 and R_2 must also be 24 volts. The current through R_1 must be

$$I = \frac{24}{20} = 1.2 \text{ amps}$$

The current through R_2 must be

$$I = \frac{24}{30} = .8 \text{ amps}$$

(w) 20 volts. If the current through R_2 is 1 amp, and the resistance of R_2 is 10 ohms, then the voltage across R_2 must be

$$E = 1 \times 10 = 10 \text{ volts}$$

Since R_2 and R_3 are in parallel, then the same voltage must be across R_3, and therefore the same current of 1 amp will flow through it, giving a total current of 2 amps through R_2 and R_3. This current of 2 amps must flow through R_1 and since R_1 has a resistance of 5 ohms, the voltage drop across it must be

$$E = 2 \times 5 = 10 \text{ volts}$$

Since the source voltage in any circuit is equal to the sum of the voltage drops around the circuit, the source voltage in this case must be 20 volts.

(x) The total resistance is 31 ohms. To solve this problem we must find the resistance of R_2, R_3 and R_4 in parallel and also the resistance or R_6 and R_7 in parallel. We can substitute an equivalent for these two parallel groups; then we have a simple series circuit and we can find the total resistance of this circuit simply by adding the individual resistances.

Since R_2, R_3 and R_4 are each 12-ohm resistors, then the total resistance of the three resistors in parallel will be one-third the resistance of any one of the resistances or one-third of 12 which is 4 ohms.

The resistance of the parallel combination of R_6 and R_7 can be found using the parallel resistance formula

$$R_t = \frac{48 \times 24}{48 + 24} = 16 \text{ ohms}$$

Now substituting 4 ohms for the parallel combination R_2, R_3 and R_4 and 16 ohms for the parallel combination of R_6 and R_7 we have a series resistance circuit. The total resistance of this circuit will be

$$R_t = 5 + 4 + 6 + 16 = 31 \text{ ohms}$$

(y) In a series-parallel circuit, the current is the same in each series branch of the circuit.

(z) In a parallel branch of a series-parallel circuit, the sum of the currents through the branches of the parallel circuit is equal to the total current flowing in the series part of the circuit.

Lesson Questions

Be sure to number your Answer Sheet B104-1.

Place your Student Number on every Answer Sheet.

1. What is the total resistance of three 15-ohm resistors connected in series?

2. What is the total resistance of three 15-ohm resistors connected in parallel?

3. A 3-ohm, a 5-ohm and a 4-ohm resistor are connected in series across a battery. The voltage drop across a 3-ohm resistor is 6 volts. What is the battery voltage?

4. If three resistors are connected in series across a 12-volt battery, and the voltage drop across one resistor is 3 volts and the voltage drop across the second resistor is 7 volts, what is the voltage drop across the third resistor?

5. If four resistors are connected in parallel and R_1 equals 12 ohms and R_2 equals 9 ohms, R_3 equals 24 ohms and R_4 equals 18 ohms, what is the resistance of the parallel combination?

6. R_1 and R_2 are two resistors of the same value connected in parallel. This parallel combination is connected in series with R_3, a 10-ohm resistor. The series-parallel network is connected to a 15-volt battery. If the voltage across R_3 is 10 volts, what are the values of R_1 and R_2?

7. If two resistors are connected in parallel, will the voltage drop across the two be (1) equal, (2) greater across the larger resistor, (3) greater across the smaller resistor?

8. Resistors R_1 and R_2 are connected in parallel. The resistance of R_1 is 4 ohms, and the current through it is 2 amps. The current through R_2 is .5 amps. Find the resistance of R_2.

9. Three 6-ohm resistors are connected in parallel. A fourth 6-ohm resistor is connected in series with the parallel combination. The series-parallel network is connected to a battery with the free end of the single 6-ohm resistor going to the positive terminal. Draw a schematic diagram of the circuit.

10. In the circuit of Question 9, if the battery voltage is 8 volts, what will the voltage across the three parallel-connected resistors be?

HOW TO CONCENTRATE

The secret of rapid progress with any course of study lies in being able to concentrate. If your mind wanders from study while you are alone in a quiet room, try moving to a noisy room, or try tuning in an all-musical program on the radio. Stay away from loud conversations, though.

If noise definitely bothers you, however, do your studying in a quiet location. If you feel too sleepy to concentrate, the room may be too hot. Open the windows, and put on a coat if necessary, for it is easier to study in a cool room. Sponge your face, neck and eyes with cold water.

If you have difficulty in understanding a subject, write down an explanation of it in your own words, or try outlining the subject and studying your outline. Underlining important words as you study is another aid to learning.

Try different studying techniques, until you find the one that gives you complete mastery of a subject in the shortest possible time. The faster you master each lesson, the sooner you'll complete the Course and be ready for a good job in electronics.

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ACHIEVEMENT THROUGH ELECTRONICS

HOW RESISTORS ARE USED

B105-1

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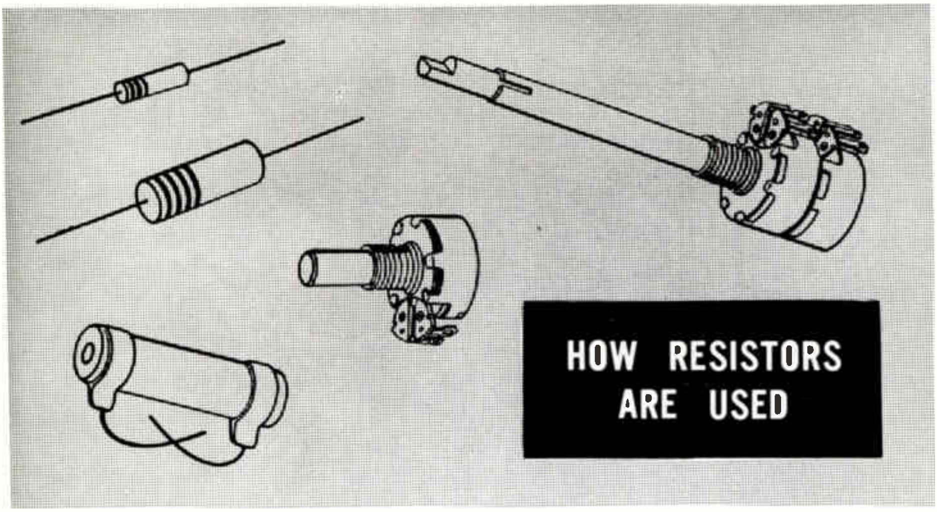
HOW RESISTORS ARE USED

B105-1

STUDY SCHEDULE

For each study step, read the assigned pages first at your usual speed, then reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind. Study each other step in the same way.

JDL3M1174 **1974 EDITION** **Litho in U.S.A.**



HOW RESISTORS ARE USED

This is the first lesson in your NRI course that will be devoted almost entirely to one electronic part - resistors. In your next lesson you will study coils in detail, and in the following lesson you will study capacitors. These three parts - resistors, coils and capacitors - along with tubes and transistors are the most important parts in electronic equipment. You will find more resistors in electronic equipment than any other part. Therefore it is important that you learn how they are used so that you will be able to tell whether or not a particular circuit is working properly, and also so that you will be able to select a suitable replacement for a resistor in a circuit, when a replacement is needed.

Resistors, coils, and capacitors are important, not only because they are used so often in electronic equipment, but also understanding how these parts work will help you to understand how other parts work. For example, a transformer is nothing more than a group of coils wound on a single core. If you understand how a single coil works, then you will be much better prepared to understand how several of them work when used together to make up a transformer.

Resistors perform in essentially the same way in both ac and dc circuits. However, you will find when you study coils and capacitors that this is not true of these parts. Actually, coils and capacitors have little or no value in dc circuits. They are primarily used in ac circuits. Therefore, when you study coils and capacitors, you will be learning more about these parts, and we will also go into more detail about ac and how it acts in circuits where these parts are present.

WHY RESISTORS ARE IMPORTANT

Resistors are found in practically every piece of electronic equipment. As a technician you will have to replace many resistors. As we mentioned earlier, there are more resistors used in electronic equipment than any other parts.

Sometimes when you have to replace a resistor you will be able to refer to the schematic diagram of the equipment, find the value of the resistor and simply go ahead and install a new resistor in the circuit. However, you will find that on many occasions you will have to work on electronic equipment for which there is no diagram available and the original resistor may have been burned so badly that you will be unable to tell what its value was. Then, you will have to fall back on your knowledge of electronic circuits to decide what size resistor to use. What you will learn in this lesson will prepare you for this type of work.

There are many uses for resistors in electronic equipment. The various electrodes in a tube or transistor used in a piece of electronic equipment do not all require the same operating voltages. However, for economy, the required operating voltages must all be obtained from a single power supply. Resistors are used to drop the voltage to the correct value for the tube or transistor.

Resistors are used to isolate parts from each other, so that one will not interfere with the operation or the action of each other.

Special variable resistors called potentiometers are used to control the volume and tone in radio and TV receivers, to control the picture brightness and contrast in black and white and color TV receivers, and to adjust the tint and color saturation of the picture in color sets.

There is no end to the uses to which resistors are put in electronic equipment, and therefore it is extremely important that you understand how they are used.

TYPES OF RESISTORS

You already know that there are several types of resistors used in electronic equipment. The most frequently encountered resistor is the carbon resistor, which as we mentioned before is simply a carbon compound which is held together by a cement-type of binder. Carbon resistors are made chiefly in 1/2-watt, 1-watt and 2-watt sizes. Occasionally you will run into very small carbon resistors that are 1/3-watt resistors, but these are not used too often. You will learn more about the watt, which is the unit of power measurement, later in this lesson.

You will soon learn to recognize the wattage rating of a resistor by its size. The resistors shown in Fig. 1 are 1/2-watt, 1-watt and 2-watt carbon resistors. The body of the resistor in each case is drawn full size to give you an idea of how big each type of resistor is.

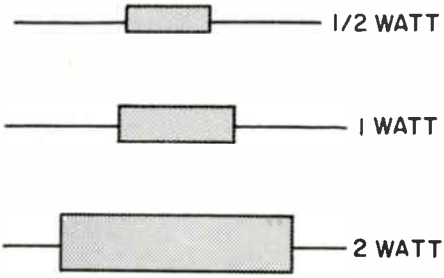


Fig. 1. Relative physical size of the three different wattage carbon resistors usually found in electronic equipment.

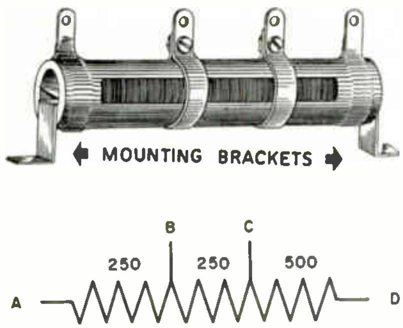


Fig. 2. A tapped wire-wound resistor and its schematic symbol.

In addition to carbon resistors you will run into wire-wound resistors. A wire-wound resistor is made by winding a resistance wire on a form. Wire-wound resistors are found with wattage ratings of 3 or 4 watts up to very high wattage ratings.

In some electronic equipment you will find tapped wire-wound resistors that look like the resistor shown in Fig. 2. The total resistance of this resistor is 1000 ohms. This is the resistance you would measure between terminals A and D. However, there are two taps on the resistor; these are the taps B and C. The resistance between terminal A and B is 250 ohms and the resistance between terminals B and C is 250 ohms. The remaining resistance between terminals C and D is 500 ohms. This type of resistor is usually quite a large resistor and in most cases it is mounted on the chassis by means of mounting brackets which hold it in place. The resistor is so large and heavy that if it were simply held in place by wires connected to the various terminals, the chances are that if the equipment received any jarring or bouncing the resistor would break loose from the wires.

Metal oxide resistors are also widely used in modern electronic equipment. These resistors can be made in higher wattage ratings than carbon resistors, and still have many of the advantages of the carbon resistors. The wire-wound resistors are made by winding wire in the form of a coil on an insulated support such as a ceramic type rod. Since the resistor is made of a coil of wire it takes on some of the characteristics of a coil. In some circuits this may be undesirable and in applications of this type a metal oxide resistor can be used. It is made by depositing a metal oxide film on a ceramic or glass tube or rod. The oxide film is in the form of a continuous path rather than a coil and therefore does not act like a coil.

You will also run into variable resistors such as shown in Fig. 3. The resistor shown in Fig. 3A is a wire-wound type of variable resistor and is usually called a rheostat. Notice that this type of resistor has only two terminals. Another rheostat is shown in Fig. 3B. This rheostat can either be a wire-wound control similar to the one shown in A or it might have a carbon element and a slider that rotates along the

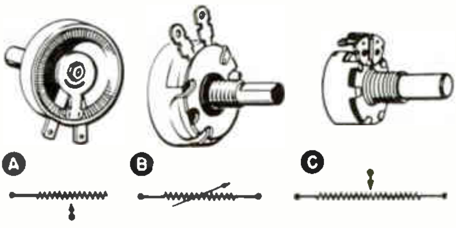


Fig. 3. Variable resistors and the symbols for them. A and B are rheostats, and C is a potentiometer.

carbon element to provide the required resistance between the two terminals. The variable resistor shown in Fig. 3C is called a potentiometer. This variable resistor has three terminals. The resistance between the two outside terminals remains constant and the slider moves on the resistance element so the resistance between the center terminal and the other two may be varied. A control of this type may be a wire-wound control or it can also be a carbon control. Most potentiometers are fairly high resistance units and are carbon controls. However, in some applications, for example in color TV receivers, you will run into some very low resistance potentiometers, and these are wire-wound controls. Potentiometers will be found in all types of electronic equipment.

In electronic equipment you will run into all three types of resistors: carbon, wire-wound, and deposited-film. Most often these will be fixed resistors; in other words, they will have a certain value which cannot be changed.

You will also encounter many tapped resistors; this type resistor is always a wire-wound resistor.

In addition, you will run into variable resistors; these may be either wire-wound or carbon resistors. If a variable resistor has two terminals it is called a rheostat; if it has three terminals it is called a potentiometer.

Thus resistors are classified as carbon, wire-wound, and deposited-film; these resistors may be either fixed, tapped, or variable. Variable resistors are divided into rheostats and potentiometers.

Now let's study some of the important uses of resistors.

Using Resistors To Reduce Voltage

We mentioned earlier that in a radio or TV receiver as well as industrial control equipment, many different operating voltages may be required, and these voltages must be obtained from a single power supply to keep down the cost of the equipment. Resistors are often used to reduce the voltage from the power supply to the required value.

SERIES-DROPPING RESISTORS

One of the most common applications of a resistor where it is used to drop voltage is the series-dropping resistor. In this case, the resistor is placed in series with the load, and the current flowing through it produces a voltage drop across the resistor. Small table model radio receivers are an example in which this use of a resistor may be found. In these radio receivers, the heaters of the various tubes are connected in series and they are operated directly from the power line. However, in some cases, the total voltage required by the heaters connected in series may be somewhat less than the power line voltage. In such a case, a resistor is placed in series with the heaters, and part of the voltage is used up by the resistor so that each tube heater gets the correct voltage.

An example of a circuit of this type is shown in Fig. 4. Here we have four tubes with their heaters connected in series. Notice that three of the tubes operate with a heater voltage of 12.6 volts. When the three tubes are connected in series they will require three times this voltage or 37.8 volts. These three tubes are connected in series with the fourth tube that operates with a heater voltage of 50 volts so that the total voltage required by the four tubes in series is 87.8 volts. However, to operate this string of four tubes from a 120-volt power line means that we have to get rid of approximately 32 volts in some

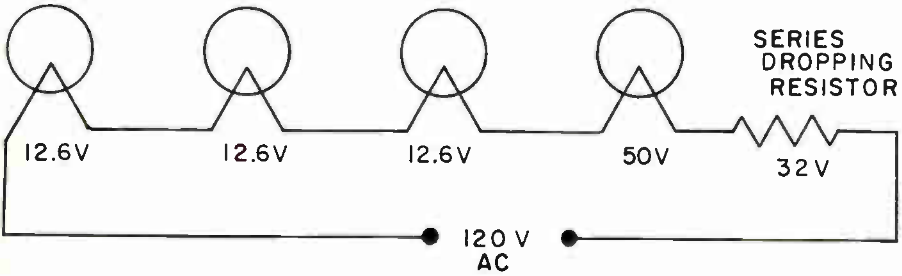


Fig. 4. A series tube heater string, with a series-voltage-dropping resistor.

way in order to get the correct voltage on each tube. Here the series-dropping resistor is connected in series with the tubes. If the tubes operate with a heater current of .15 amps, you can find the value of the resistor required by using Ohm's Law

$$R = \frac{E}{I}$$

and substituting 32 for E and .15 for I, we would find that a resistor with a resistance of 213 ohms would be required. Actually, it probably would be impossible to get a 213-ohm resistor but a 210-ohm or a 215-ohm resistor would certainly be close enough. As a matter of fact, even with a 200-ohm resistor in the circuit, the heater voltage on the tubes would be only slightly over the rated value and should not appreciably affect tube life.

Series-dropping resistors of this type are also to be found in some television receivers. Of course, in the TV receiver there will be far more tubes, and the chances are that the voltage that the resistor must drop will be less than the value in the preceding example, but its purpose is the same, to reduce the line voltage to the value required by the series-heater string.

Series-dropping resistors are also used in dc circuits An example of this type of arrangement is shown in Fig. 5. Here the load, which is represented by R_2, requires an operating voltage of 100 volts. The power supply voltage is 250 volts. The series-dropping resistor R_1 is used to reduce or drop the power supply voltage from 250 volts down to 100 volts for the load. This means that there will be a voltage drop of 150 volts across the series-dropping resistor.

The value of resistance required in R_1 will depend upon the resistance of R_2. Normally the load will have a certain resistance, and when it is operated at the correct voltage a certain current will flow through the resistance. As an example, if the resistance of R_2 is 50,000 ohms, when a voltage of 100 volts is applied across this load, a current of 2 ma will flow through it.

We can use this information to determine the value of the series-voltage-dropping resistor. We know that we must drop a voltage of 150 volts, and since it will be in series with R_2, the current flowing through it will be the same as the current through R_2, in other words 2 ma.

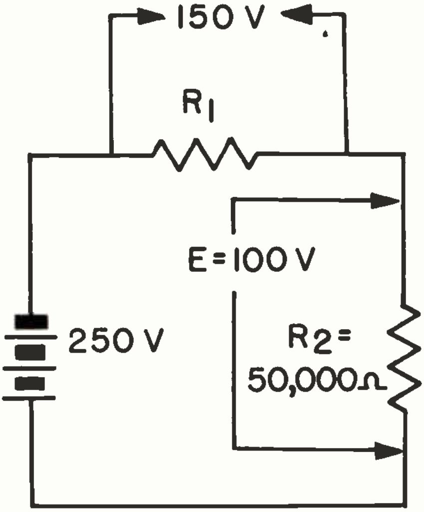


Fig. 5. The series-voltage-dropping resistor is used to reduce the power supply voltage from 250 volts to 100 volts for the load R_2.

We can use this information and Ohm's Law to find the value of R_1.

$$R = \frac{E}{I}$$

$$R = \frac{150}{.002} = 75{,}000 \text{ ohms}$$

In this particular instance we do not even have to resort to Ohm's Law to find the value of R_1. We know the resistance of R_2 is 50,000 ohms and it will have a voltage of 100 volts across it. We want R_1 to have 150 volts across it or 1-1/2 times the voltage across R_2. Therefore the resistance of R_1 must be 1-1/2 times the resistance of R_2. Since R_2 has a resistance of 50,000 ohms, then R_1 must have a resistance of 75,000 ohms.

An arrangement of this type works out very nicely as long as the resistance of R_2 remains constant. However, in many cases in electronic equipment the resistance of the load varies. When this happens, the total resistance in the circuit will vary and this will cause the current to vary. When the current in the circuit varies, the voltage drop across R_1 will vary and when this happens, the voltage across R_2 will also vary. In some cases a fairly wide variation in voltage across R_2 will not present any problem, but there are many applications where we may want to keep the voltage across R_2 reasonably constant. Under these circumstances a simple series-dropping resistor of the type shown in Fig. 5 is not particularly satisfactory.

Let us look at Fig. 6 to see how a variation in the resistance of R_2 can affect the voltage across it. Notice that here we have represented R_2 as the variable resistance load. Suppose the resistance of R_2 goes down to 25,000 ohms. Now, we have a total resistance in the circuit of 25,000 ohms for R_2 and 75,000 ohms for R_1. This means the total resistance in the circuit will be 100,000 ohms. Using Ohm's Law we find that the current will be

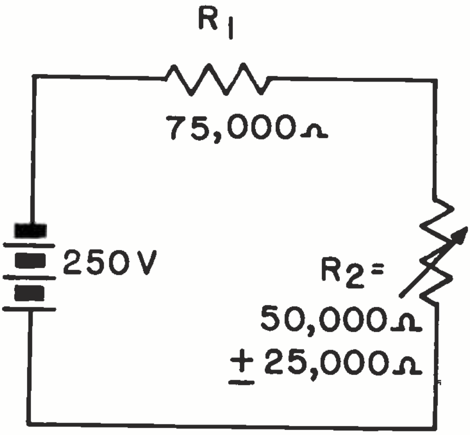


Fig. 6. When the value of R_2 varies, the voltage across it will also vary.

$$I = \frac{E}{R}$$

$$I = \frac{250}{100{,}000} \text{ amps}$$

We can multiply the numerator in this expression by 1,000 and get our answer directly in milliamperes, or perform the division as indicated. If we perform the division as indicated we will find that the current is .0025 amps. If we multiply by 1,000 first, we will get our answer in milliamperes, and in this case

$$I = 2.5 \text{ ma}$$

In either case, we see that the current has increased from 2 ma to 2.5 ma. Now the voltage drop across R_1 will be greater than 150 volts. The actual voltage drop will be 187.5 volts. Since the power supply voltage is 250 volts this leaves us with a voltage of 62.5 volts across the load.

Now let us see what happens when the resistance of R_2 increases. Suppose a resistance of R_2 increases by 25,000 ohms and becomes 75,000 ohms. Now we have R_1 and R_2 in series and since each resistor has a value of 75,000 ohms, half of the voltage will be across each resistor. This means that the voltage across R_2 will increase from 100 volts to 125 volts.

From the preceding we see that if the resistance of R_2 does change, we get quite a substantial voltage variation across the resistor. If the resistance goes down 25,000 ohms, the voltage across the load drops to 62.5 volts, and if the resistance goes up 25,000 ohms, the voltage goes up to 125 volts. A change of this type could appreciably affect the performance of a circuit and in most cases we would have to take steps to prevent such a wide voltage variation.

BLEEDER RESISTORS

Wide voltage variations such as we encountered in the circuit shown in Fig. 6 can be reduced substantially by means of a bleeder resistor. Fig. 7 shows how a bleeder resistor is connected into the circuit. Notice that the bleeder, R_3, is connected in parallel with the load R_2.

The idea in back of the bleeder is to help keep the current flowing through R_1 constant. If the current flowing through R_1 is constant then the voltage drop across it will be constant and this in turn will mean that the voltage across the load will remain constant.

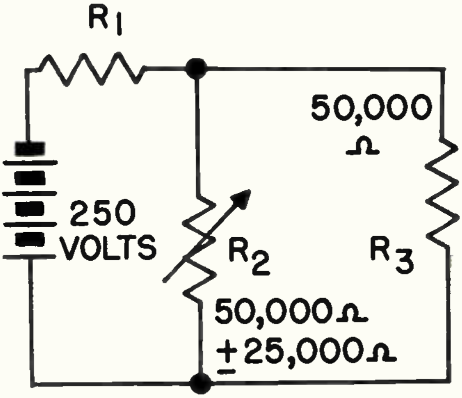


Fig. 7. The bleeder resistor R_3 is connected in parallel with the load R_2 to stabilize the voltage across the load.

The higher the bleeder current, the more closely we can keep the voltage constant across the load. This is due to the fact that if the bleeder current is large, it makes up most of the current flowing through R_1, and since it will remain constant, the current changes through R_1 due to variations in the load resistance will be held to a minimum.

Let us look at an example and see how the bleeder actually can help regulate the voltage. Let us take R_2 with a nominal resistance of 50,000 ohms, as before, and connect a bleeder resistor, R_3, in parallel with R_2. Let us select a bleeder that also has a resistance of 50,000 ohms. As before, we want to maintain the voltage across the load constant at 100 volts.

With a voltage of 100 volts across the load resistor, with its value at 50,000 ohms, the current through the load will be 2 ma as before. Since the bleeder is in parallel with the load, 2 ma will also flow through it. This means that the total current in the circuit will be 4 ma.

Now we need to select a series-dropping resistor, R_1. As before, since the power supply voltage is 250 volts, the series-dropping resistor must drop 150 volts. Going back to Ohm's Law, we have

$$R_1 = \frac{150 \text{ volts}}{.004} = 37{,}500 \text{ ohms}$$

Therefore with a series-dropping resistor of 37,500 ohms we will get a voltage drop of 150 volts across R_1, and with a load, R_2 of 50,000 ohms, and a bleeder of 50,000 ohms we will have a voltage of 100 volts across the load and across the bleeder.

With the load and the bleeder in parallel, the total resistance of the two in parallel will be 25,000 ohms. Remember that they are of equal value and therefore the parallel resistance is one-half the resistance of either resistor. Now let's see what happens when the value of R_2 decreases to 25,000 ohms. We will see how this affects the voltage across the load.

When R_2 goes down to 25,000 ohms, we have the 25,000 ohms load in parallel with the 50,000 ohms bleeder. The parallel resistance of the combination is 16,666 ohms which we can round off to 16,500 ohms to simplify our calculations. Total resistance in the circuit will be 16,500 plus the resistance of R_1, which is 37,500 ohms, or a total of 54,000 ohms. The current that will flow in the circuit can be found from Ohm's Law

$$I = \frac{250}{54{,}000} = .0046 \text{ amps}$$

A current of .0046 amps (4.6 ma) flowing through R_1 will produce a voltage drop of

$$E = .0046 \times 37{,}500 = 172.5 \text{ volts}$$

With a voltage drop of 172.5 volts across R_1, the remainder of the voltage will be dropped across R_2 and the bleeder resistor R_3. Subtracting 172.5 from 250 will give us 77.5 volts. Remember that in the preceding example shown in Fig. 6, when the value of R_2 went down to 25,000 ohms, the voltage across it dropped to 62.5 volts. Simply connecting the bleeder resistor with the same value as the nominal value of R_2 in parallel with the load improved the voltage regulation by 15 volts when the resistance of R_2 went down.

When the resistance of R_2 increases by 25,000 ohms, you will have the load R_2, which will then have a resistance of 75,000 ohms, in parallel with the bleeder R_3, which has a resistance of 50,000 ohms. The parallel combination of a 75,000-ohm and a 50,000-ohm resistor will give us a parallel resistance of 30,000 ohms. This resistance in series with R_1 will give us a total resistance of 67,500 ohms in the circuit. With this resistance in the circuit the current flow in the circuit will be .0037 amps and the voltage drop across R_1 138.75 volts. This means that the remainder of the voltage will appear across the load and bleeder and in this case would be 111.25 volts. This compares with the voltage of 125 volts which we found we would get across the load without the bleeder when the resistance of the load increased by 25,000 ohms.

In other words, without a bleeder connected across the load, as the value of the load resistance varied 25,000 ohms above and below its nominal value of 50,000 ohms, its voltage varied from 62.5 volts to 125 volts. With a 50,000-ohm bleeder connected across the load, when the load resistance varied 25,000 ohms above and below its nominal value, the voltage across the load varied from 77.5 volts to 111.25 volts. You will notice that connecting the bleeder in parallel with the load has had a substantial effect in maintaining a more constant voltage across the load.

The larger the bleeder current, the better the voltage regulation will be. In fact, if the nominal value of R_2 is 50,000 ohms and we put a 5,000-ohm bleeder in parallel with it we get very little voltage change at all as the resistance of R_2 varies between 25,000 and 75,000 ohms. With a bleeder of this size, the total series current flow would be about .022 amps. This would require a series-dropping resistor of approximately 6800 ohms. When the resistance of R_2 dropped from 50,000 ohms to 25,000 ohms, the current in the circuit would increase from .022 amps to slightly less than .023 amps. The increase in the voltage drop across R_1 would be only 4 volts, which means that the voltage drop across the load would change from 100 volts to 96 volts. Similarly, if the resistance of R_2 increased from 50,000 ohms to 75,000 ohms, the current in the circuit would drop only about one half a milliampere and the voltage drop across R_1 would change from 150 volts to approximately 147 volts. Therefore the voltage across the load would increase to 103 volts. As you can see, with a low-resistance bleeder that draws a high bleeder current, the voltage across the load remains almost constant, even with the same variation in the load that produced a wide voltage variation before.

Since a bleeder that draws a large current regulates the voltage so well you might wonder what the problem is. In a circuit where we want to keep the voltage across the load constant, why not simply put a bleeder across the load that will draw a high current and maintain the voltage constant? The answer is that the bleeder current serves no purpose other than to regulate the voltage across the load. In so far as performing any other function is concerned, it is wasted. There is a limit to how much current we can take from a power supply. The more bleeder current we draw the bigger and more costly the power supply must be. Therefore in applications where a bleeder is used, in most cases some compromise is reached and a value of bleeder is selected that will give the voltage regulation required, and no more. Of course in some applications where very precise regulation is required, we have to waste the power in the bleeder in order to get this regulation. In this case, we must build a power supply capable of supplying the required current even though it may be quite costly.

Series-dropping resistors and bleeders are often used in tube and transistor circuits. You have already studied the triode tube and will remember that it has three elements, a cathode, a grid and a plate. The pentode tube is a tube with five elements. It has the same three elements as the triode tube plus a suppressor grid and a screen grid. The suppressor grid is usually connected to B- or to the cathode. The screen grid is connected to B+ and usually operated at a voltage somewhat less than the plate voltage. The voltage required for the screen is obtained through a series-dropping resistor from the same power supply that supplies the plate voltage. If the screen voltage must be maintained constant then you will often find a bleeder in the screen circuit for this purpose.

SUMMARY

Now let us review what you have studied in this section on resistors and how they are used to reduce voltage. Resistors are sometimes used in the heater circuit of small radios or in the heater circuit of television receivers to reduce the line voltage to the value required by series-connected tube heaters. Resistors are also used to reduce the voltage to a load so that the load can be operated from a power supply that has a somewhat higher voltage than the voltage required by the load.

Resistors are used as bleeders to stabilize or regulate the voltage across a load. The bleeder consumes or wastes a certain amount of current, but this extra current that flows through the bleeder remains constant and helps maintain the voltage drop across the series-dropping resistor constant. The larger the current consumed by the bleeder in comparison to the current consumed by the load, the better the regulation across the load will be. However, since the bleeder current is waste current and performs no useful purpose other than to regulate the voltage across the load, we normally do not use any more bleeder current than is necessary to get the degree of regulation that is required across the load. We keep the bleeder current as low as possible in order to keep the cost and size of the power supply as low as feasible. However, in some applications where very precise regulation is required, a large bleeder current is used and we simply have to go to the expense of making the power supply as large as necessary to supply this current along with the load current.

Now to help you be sure that you understand this section of the lesson and to review it, answer the following self-test questions.

SELF-TEST QUESTIONS

(a) What is the purpose of a series-dropping resistor?

(b) If two tubes that each require a heater voltage of 35 volts are connected in series with two additional tubes that require a heater voltage of 6 volts each and the four heaters connected in series are to be operated from a 120-volt power line, how much voltage must the series-dropping resistor drop in order to provide the correct heater voltages for the tubes?

(c) In the preceding example, if the current drawn by the tubes is .3 amperes, what would be the value of the series-dropping resistor to use?

(d) What is the purpose of a bleeder?

(e) Which type of bleeder is more effective, a high-resistance bleeder that draws very little current, or a low-resistance bleeder that draws a substantial current?

(f) What consideration other than regulation must be kept in mind in selecting a bleeder?

(g) If a load, which has a resistance of 20K ohms and requires an operating voltage of 200 volts, is connected across a power supply that has an output voltage of 300 volts, what should the resistance of the series-voltage-dropping resistor be?

Power In Electrical Circuits

We have already mentioned several times that the unit of electrical power is the watt. The watt tells us how much electrical energy or power is being expended or used in a circuit. You have probably run into this unit many times, and you are no doubt familiar with different size light bulbs - they are rated in watts. A 60-watt bulb consumes 60 watts of electrical energy when it is lit. A 100-watt electric bulb consumes 100 watts of electrical energy - almost twice as much power as a 60-watt bulb.

Now let us go ahead and learn more about exactly how much electrical energy the watt represents.

THE WATT

The power in an electrical circuit is equal to the product of the voltage times the current. Expressing this as a formula we have

$$P = E \times I$$

We generally drop the times sign and simply write the formula as

$$P = EI$$

This formula tells us that if a generator is supplying a voltage of 1 volt to a circuit and the current flowing in the circuit is 1 amp, the power being supplied by the generator is 1 watt. If the generator is supplying a voltage of 10 volts and a current of 2 amps, the power being supplied by the generator is 10×2 =20 watts.

From the expression for power we see that the current used by a 100-watt electric light bulb will be slightly less than 1 amp when the bulb is operated from a 120-volt power line. Since the product of the voltage times the current equals 100 watts, we can find the current by rearranging the power formula to

$$I = \frac{P}{E}$$

and substituting 100 watts for P and 120 volts for E

$$I = \frac{100}{120} = .83 \text{ amps}$$

A 60-watt bulb will draw somewhat less current,

$$I = \frac{60}{120} = .5 \text{ amps}$$

The power in an electrical circuit can also be expressed in terms of voltage and resistance or in terms of current and resistance by combining the power formula with Ohm's Law. For example from Ohm's Law we know that

$$E = I \times R$$

If we substitute I × R for E in the power formula we have

$$P = I \times R \times I = I \times I \times R$$

If we drop the times sign and write I × I as I^2 (this is called I squared) we will have the formula

$$P = I^2R$$

You will see this expression many times in electronics. Remember that the term I^2 means I × I. This form of the power equation is often used to determine the wattage rating of a resistor in a circuit where the current through the resistor and the resistance of the resistor are known.

Going back to our original power formula

$$P = E \times I$$

and Ohm's Law in the form

$$I = \frac{E}{R}$$

if we substitute $\frac{E}{R}$ for I we will get

$$P = E \times \frac{E}{R}$$

which we usually write as

$$P = \frac{E^2}{R}$$

where the expression E^2 means E × E. This form of the power equation can be used where we know the voltage across a part and the resistance of the part or circuit.

These three forms of the power formula are extremely important; you will have many occasions to use them. Therefore you should take the time now to memorize them to save having to look them up in the future. Even though you may not have to do a great deal of calculating involving these formulas you should know what the formulas are so you will be able to approximate the power used in a circuit. The three formulas are:

$$P = EI$$

$$P = I^2R$$

$$P = \frac{E^2}{R}$$

WATTAGE RATING OF RESISTORS

Earlier we mentioned that resistors were made with different wattage ratings. When current flows through a resistor a certain amount of power is used, or as we say dissipated. The wattage rating of a resistor tells us how much power the resistor can dissipate. If the power being dissipated by the resistor is greater than its wattage rating, the resistor will soon burn out.

We mentioned previously that carbon resistors are made in 1/2-watt, 1-watt and 2-watt sizes. Also, you will occasionally run into very small carbon resistors that are rated at 1/3-watt.

When we say that a resistor is a 1-watt resistor we mean that the power it can dissipate or handle is 1-watt. This means that the product of the current squared through the resistor times the resistance of the resistor must be equal to 1 watt or less.

Actually, in the case of carbon resistors, it is not a good idea to use them at their maximum rating. Carbon resistors have a tendency to change value if they get too hot. A 1-watt carbon resistor that is actually dissipating one full watt of electric power will get quite warm after it has been in operation for some time. Eventually, this will cause the resistor to change value. There is no way of predicting how much the resistor will change value - the change might be slight and may not affect the performance of the circuit. On the other hand, the change might be large enough to appreciably affect the performance of the circuit. The usual practice is to use resistors having a wattage rating almost double that actually required. In other words, if the power that a resistor must dissipate is 1 watt or slightly over 1 watt then you would use a 2-watt resistor. If the resistor must dissipate approximately 1/2 watt, it is best to use a 1-watt resistor to avoid any possible problem in the future due to the resistor overheating and changing value.

The deposited film type of resistor is made in ratings of 2 watts up to about 10 watts. These resistors are somewhat larger than carbon resistors and are able to handle the larger power. They do not have the tendency to change value that carbon resistors have and therefore can be operated closer to their full wattage rating. However, even in the case of deposited film resistors, most manufacturers usually allow a reasonable safety factor to prevent the resistors burning out after they have been in service for some time. As an example, if the wattage being dissipated by a deposited film resistor is almost four watts, a 5-watt resistor is usually used to provide some safety factor.

There is almost no limit to the wattage ratings in which wire-wound resistors can be made. In radio and television receivers you will seldom find wire-wound resistors rated at higher than 50 watts. However, in radio and TV transmitting equipment and in industrial control equipment you may find wire-wound resistors that are capable of dissipating several thousand watts or more. These high-wattage resistors are made with a large-size resistance wire that can carry the high current and are wound on a large diameter tube in order to provide room for the wire needed to get the required resistance.

The same safety rule for carbon resistors is generally followed in the case of wire-wound resistors. Usually a resistor having approximately twice the wattage rating that the resistor must dissipate is used. Manufacturers follow this practice because the larger wattage resistor will be a larger physical size and better able to get rid of the heat that is produced by the electrical energy that the resistor must dissipate and also because it provides a safety factor - there is far less chance of the resistance wire burning out if the overrated resistor is used.

TRANSFERRING POWER

A common problem in electronics is transferring power from one circuit to another or from one device to another. As an example, consider the output tube or transistor in a radio receiver and the loudspeaker in the receiver. The output tube or transistor develops audio power; in other words it develops sound power in electrical form. The problem is to get the maximum amount of power over to the speaker from the output tube or transistor. Now let us consider what is involved in this power transfer.

The tube or transistor acts as the power source. The speaker acts as a load. Thus we have a situation somewhat similar to a battery with a load connected across it. We have seen this circuit many times.

However, there is one thing we have omitted in the circuits we have looked at before. All electrical parts have resistance. This is true of transistors, tubes, coils, transformers, generators and batteries. The usual practice is to simply represent a battery by the battery symbol. However, to be precise, we should represent it by the battery symbol and a resistor in series with it to represent the internal resistance of the battery. By internal resistance of the battery we mean the opposition that current encounters in flowing from the positive terminal of the battery through the battery to the negative terminal.

In Fig. 8 we have shown a circuit representing a battery with internal resistance and a load connected across the battery. The battery we have shown is a 10-volt battery with an internal resistance of 5 ohms. Thus in any circuit we consider, the total resistance in the circuit will be the resistance of R_1 plus the internal resistance of the battery, which is 5 ohms. This total resistance is the opposition to current flow in the circuit, and is the value we must use in performing any calculations to find the current flowing in the circuit or the power dissipated in the circuit.

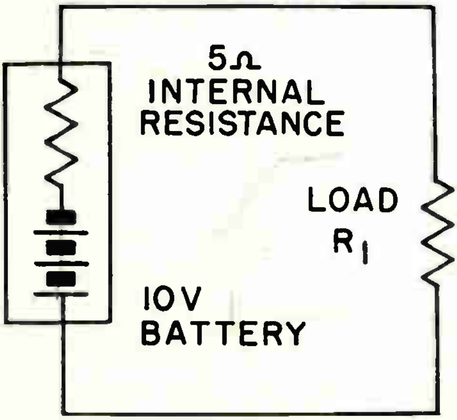


Fig. 8. Circuit representing a battery with internal resistance and a load across the battery.

The fact that the battery has internal resistance brings about several interesting things. First, let us assume that the resistance of R_1 in the circuit is 20 ohms; this means that the total resistance in the circuit will be 25 ohms. Since the battery potential is 10 volts this means that the current flowing in the circuit will be

$$I = \frac{10}{25} = .4 \text{ amps}$$

The .4 amps flowing through the battery resistance will produce a voltage drop across this resistance. This voltage drop will be

$$E = .4 \times 5 = 2 \text{ volts}$$

Thus the actual voltage available at the battery terminals will be only 8 volts. This is quite common in batteries and generators; part of the voltage produced by the battery or generator is lost due to the internal resistance of the device.

Now let us find how much power is actually being supplied by the battery, and how much is being received by the load. The power supplied by the battery is equal to the battery voltage times the current or $P = 10 \times .4 = 4$ watts.

The power being dissipated by the load can best be found by the power formula

$$P = I^2R$$
$$P = .4 \times .4 \times 20 = 3.2 \text{ watts}$$

Now let us replace the 20-ohm resistor that we have in the circuit for R_1 with a 10-ohm resistor and see what happens in the circuit. With a 10-ohm resistor in the circuit the total resistance in the circuit will be 10 ohms plus the 5 ohms internal resistance of the battery or a total of 15 ohms. The value of the current in the circuit will be

$$I = \frac{10}{15} = .67 \text{ amps}$$

Now the power being supplied by the battery will be

$$P = 10 \times .67 = 6.7 \text{ watts}$$

and the power dissipated by the resistor R_1 will be

$$P = .67 \times .67 \times 10 = 4.5 \text{ watts (approximately)}$$

If we replace R_1 with a 6-ohm resistor, we will have a total resistance of 11 ohms in the circuit. This will give us a current flow of .9 amps and the power dissipated in R_1 will be 4.8 watts.

If we substitute a 5-ohm resistor for R_1, the total resistance in the circuit will be 10 ohms and the current will be 1 amp. The power dissipated by R_1 will then be 5 watts. The total power generated by the battery will be 10 watts.

If we substitute a 4-ohm resistor for R_1 the total resistance in the circuit will be 9 ohms and the current flow 1.1 amps. The power dissipated by R_1 will then be 4.8 watts. If we continue to reduce the size of the resistance we will find that the power dissipated by the resistor will continue to go down.

Notice that as we started with a 20-ohm resistor and reduced the size of it to 5 ohms, that the power dissipated by the resistor increased until it reached a maximum value at 5 watts. When we reduced the resistance of the resistor below 5 ohms, the power starts to decrease.

The significant thing to notice here is that we obtain maximum power in the resistor when the resistance of the resistor is equal to the internal resistance of the battery.

This situation will always exist. We will get maximum power in the load when the load resistance is equal to the generator resistance. However, this condition may not always be desirable because the total power being generated by the generator when we have a 5-ohm resistance in the circuit is 10 watts. Since we are dissipating only 5 watts in the resistor, half of the power is being wasted in the battery itself. Thus, when maximum power transfer is being obtained, the over-all efficiency of the system is only 50% - half the power being produced by the source is transferred to the load. With a higher load resistance, the efficiency improves and under some circumstances we may be willing to get something less than full power transfer to get better efficiency. For example, when the value of R_1 was 20 ohms we had a power of 3.2 watts in the resistor and the total power produced by the generator was 4 watts. This is an efficiency of 80%; in other words, 80% of the power produced by the battery is transferred to the load. Even though this is less than the power we get when the load is matched or equal to the battery resistance, the efficiency of the power transfer is much better.

The important point for you to remember from this section of the lesson is that we will get maximum power transfer from a voltage source to a load when the resistance of the load is equal to the internal resistance of the source. Under these conditions we say that the load is matched to the generator. Under these conditions, the efficiency of the power transfer will be 50% - half the power will be dissipated in the load and the other half lost in the generator or the voltage source. Under some circumstances it is better to get somewhat less power transferred from the source to the load in order to get better efficiency.

SUMMARY

This section of this lesson is an extremely important one, and you should be sure that you understand it completely before going on.

You learned that the unit of power is the watt. The power in a circuit can be obtained from any one of the three formulas

$$P = EI$$

$$P = I^2R$$

$$P = \frac{E^2}{R}$$

You should memorize these three formulas; you will need them over and over again in your career in electronics.

Remember that resistors are made in different wattage ratings. Remember too, that carbon resistors have a tendency to change value if they are operated near their maximum wattage rating. If you have to replace a carbon resistor in a piece of electronic equipment you can use the same wattage rating resistor as used by the manufacturer or one having a higher wattage rating, if there is room for the larger resistor in the circuit. The usual safety factor allowed in electronic equipment is to use a resistor having twice the wattage rating that it must dissipate. This will reduce the possibility of resistor failure after the equipment has been in use for some time.

Remember that maximum transfer of power from a generator to a load can be obtained when the resistance of the load matches the resistance of the generator. When maximum power transfer is obtained the efficiency is only 50%; this means that only half the power produced by the generator reaches the load. Under some circumstances we will be satisfied with a somewhat lower power in the load in order to obtain better efficiency.

Now do the self-test questions on this section carefully. If you have difficulty with any of the questions it is a sign that you need to spend more time on this important section.

SELF-TEST QUESTIONS

(h) What is the unit of electrical power or energy?

(i) If a battery has a voltage of

15 volts, and it is supplying a current of 3 amps, what is the power being supplied by the battery?

(j) What do we mean when we say that a resistor is dissipating 10 watts?

(k) If the voltage across a 1000-ohm resistor is 100 volts, how much power is the resistor dissipating?

(l) If the voltage across a 5000-ohm resistor is 50 volts, what is the power dissipated by the resistor?

(m) If the current through a resistor is 2 amps, and the resistance of the resistor is 25 ohms, what is the power dissipated by the resistor?

(n) If the current through a 100K resistor is 10 ma, how much power is the resistor dissipating?

(o) A battery has a voltage of 9 volts and an internal resistance of 3 ohms. What size resistor should be used as a load in order to get maximum power transfer?

(p) A 20-volt battery has an internal resistance of 10 ohms. What size resistor should be be connected across it as a load in order to get maximum power transfer? How much power will be produced by the battery and how much power will be transferred by the load?

Resistor Values

We mentioned earlier that there are more resistors used in electronic equipment than any other parts. A small radio receiver generally has somewhere between ten and fifteen resistors. A black and white TV receiver usually has approximately 50 resistors and a color TV receiver may have twice that many. Usually you can figure that a piece of electronic equipment will have somewhere between three and five resistors at least, for each tube or transistor used in the equipment.

We have already gone into the methods used to indicate the value of a resistor. You know that the unit of resistance is the ohm. If the voltage across a resistor is 1 volt and a current of 1 amp flows through the resistor, the resistance of the resistor is 1 ohm. You will remember this important relationship is expressed in Ohm's Law.

You are also familiar with the fact that large values of resistors are found in electronic equipment and that we use the symbol K to represent 1000 and the letter M for megohms which represents 1,000,000 ohms. Thus a 2,200-ohm resistor will often be marked 2.2K on a diagram and a 4,700,000-ohm resistor will often be marked 4.7M or 4.7 megs.

Since there are 1000 ohms in 1K-ohm and 1,000,000 ohms in a megohm, it follows that there are 1000K-ohms in a megohm. You need to be able to convert between K-ohms and megohms because on some diagrams a resistor having a resistance of 100K-ohms may be marked as .1 meg, and you must realize that both represent the same value. To convert from ohms to K-ohms you move the decimal point three places to the left, and to convert from K-ohms to ohms you move it three places to the right. To convert from ohms to megohms you move the decimal point six places to the left and to convert from megohms to ohms you move it six places to the right. To convert from K-ohms to megohms you move the decimal point three places to the left and to convert from megohms to K-ohms you move it three places to the right. Remember that to convert from the smaller unit to the larger unit you move the decimal point to the left, and to convert from the larger unit to the smaller unit you move the decimal point to the right.

TOLERANCES

The most frequently encountered resistor is the molded-carbon resistor. The molded-carbon resistor is made with three different tolerance values. The resistor is made with a 5% tolerance, a 10% tolerance or a 20% tolerance. The tolerance indicates how much the resistor may vary in resistance from its indicated value. For example, a 100-ohm resistor with a 5% tolerance will be within 5% of 100 ohms. This means that its value might be 5% below or as much as 5% above 100 ohms. 5% of 100 is 5 ohms and therefore the resistance of the resistor may be any value between 95 and 105 ohms.

In this case of a 10% resistor, the value may vary 10% above or below 100 ohms. 10% of 100 is 10 ohms and therefore the resistance of this resistor can be any value between 90 ohms and 110 ohms. A 20% resistor can have a tolerance of 20 ohms and therefore the resistance could be any value between 80 ohms and 120 ohms.

The closer the tolerance of a resistor, the more expensive the resistor is. Thus a 5% resistor is more expensive than a 10% resistor and a 10% resistor is more expensive than a 20% resistor. However, with today's modern automatic resistor making machinery, there is very little difference between the price of a 10% resistor and a 20% resistor and therefore you don't run into too many 20% resistors in electronic equipment any more. There is considerable difference between the price of a 5% resistor and a 10% resistor, and therefore most manufacturers will use 10% resistors wherever they can. The 5% resistors are found only in the more critical circuits where it is important that the value of the resistor be held to a close tolerance.

EIA VALUES

The EIA (Electronic Industries Association) has set up standard carbon resistor values. You cannot buy any value carbon resistor you might want - you have to buy one of the standard values. The standard values are arranged so that you can get a resistor within 5% of any required value. For example, if you determined that in a certain circuit you needed a 53,000-ohm resistor, you cannot buy a 53,000-ohm carbon resistor - they are not made in this size. However, you can buy a 51,000-ohm resistor and a 56,000-ohm re-

Ohms	Ohms	Ohms	Ohms	Ohms	Ohms	Ohms	Ohms	Ohms	Ohms	Megs	Megs
0.24	1.1	5.1	24	110	510	2400	11K	51K	240K	1.1	5.1
0.27	**1.2**	**5.6**	**27**	**120**	**560**	**2700**	**12K**	**56K**	**270K**	**1.2**	**5.6**
0.30	1.3	6.2	30	130	620	3000	13K	62K	300K	1.3	6.2
0.33	**1.5**	**6.8**	**33**	**150**	**680**	**3300**	**15K**	**68K**	**330K**	**1.5**	**6.8**
0.36	1.6	7.5	36	160	750	3600	16K	75K	360K	1.6	7.5
0.39	**1.8**	**8.2**	**39**	**180**	**820**	**3900**	**18K**	**82K**	**390K**	**1.8**	**8.2**
0.43	2.0	9.1	43	200	910	4300	20K	91K	430K	2.0	9.1
0.47	**2.2**	**10**	**47**	**220**	**1000**	**4700**	**22K**	**100K**	**470K**	**2.2**	**10**
0.51	2.4	11	51	240	1100	5100	24K	110K	510K	2.4	11
0.56	**2.7**	**12**	**56**	**270**	**1200**	**5600**	**27K**	**120K**	**560K**	**2.7**	**12**
0.62	3.0	13	62	300	1300	6200	30K	130K	620K	3.0	13
0.68	**3.3**	**15**	**68**	**330**	**1500**	**6800**	**33K**	**150K**	**680K**	**3.3**	**15**
0.75	3.6	16	75	360	1600	7500	36K	160K	750K	3.6	16
0.82	**3.9**	**18**	**82**	**390**	**1800**	**8200**	**39K**	**180K**	**820K**	**3.9**	**18**
0.91	4.3	20	91	430	2000	9100	43K	200K	910K	4.3	20
1.0	**4.7**	**22**	**100**	**470**	**2200**	**10K**	**47K**	**220K**	**1 meg**	**4.7**	**22**

Fig. 9. Standard EIA carbon resistor values.

sistor and therefore you would select one of these two values - the exact one that you would select would depend upon whether you want the resistance to be a little higher than the calculated value or a little lower.

Standard EIA carbon resistor values are shown in Fig. 9. All are available with a 5% tolerance; the values in bold type are also available in 10% tolerances. You normally cannot buy 20% resistors for replacement purposes, but either 5% or 10% resistors are satisfactory replacements.

COLOR CODE

Carbon resistors are identified by means of a color code. There will be three or four colored bands on a carbon resistor. The resistors with only three color bands are 20% tolerance resistors. The resistors with the four color bands will be either 5% or 10% resistors depending upon the color of the tolerance band. If the fourth band is a gold band the resistor has a tolerance of 5%, and if it is a silver band the resistor has a tolerance of 10%.

The color bands are placed on the body of the resistor nearer to one end than the other as shown in Fig. 10. To read the color band, hold the resistor as shown in Fig. 10. The fourth band, if there is a fourth band, will be either gold or silver and it will be on the right and tell you the tolerance of the resistor. To read the value of the resis-

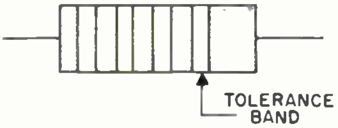


Fig. 10. Resistor values and tolerance are identified by color bands as shown.

Color	1st Figure	2nd Figure	No. of Zeros
Silver			.01
Gold			.1
Black	0	0	none
Brown	1	1	0
Red	2	2	00
Orange	3	3	000
Yellow	4	4	0000
Green	5	5	00000
Blue	6	6	000000
Purple	7	7	
Gray	8	8	
White	9	9	

Fig. 11. Standard resistor color code.

tor start at the left end. The first color band gives you the first significant figure of the resistance value. The second color band gives you the second figure and the third tells you how many zeros to add to get the resistance of the resistor.

Values assigned the various colors are shown in Fig. 11. For example, a resistor with (left to right) red, red, black, and gold bands would have a resistance of 22 ohms. The first and second bands each indicate 2; the black band indicates no zeros. The gold band indicates 5% tolerance. If the resistor were colored orange, orange, red, the first and second bands would each indicate 3, and the red band two zeros, so the value would be 3300 ohms or 3.3K. If the fourth band is silver, the tolerance is 10%, if gold 5%. If there is no fourth band, the tolerance is 20%.

If the third color band on a resistor is gold, it indicates that you multiply the first two numbers by .1 to get the resistor value. Thus a resistor coded red, red, gold, gold is 22 × .1 = 2.2 ohms, 5%. If the third color band is silver, you multiply by .01. A resistor coded red, red, silver, gold is 22 × .01 = .22 ohms, 5%.

When you start to work on your experimental kits, you will have to use the color code to identify the various resistors in the kit. It is worthwhile to memorize the color code. However, do not spend a great deal of time trying to do it all at once. Look over the color code shown in Fig. 11 two or three times and learn at least what a few of the colors represent. Then after you have finished this lesson go back and take a look at it again and read it through two or three times. If you will do this several times, this, and working with your experimental kits, will soon teach you the code so that you will know it by heart. In your early experimental kits we will give you the resistance value and the color code to help you learn the code and learn to identify the resistors, but you must learn to do this yourself so you will be able to identify resistors in any electronic equipment you may be called upon to maintain or service.

DEPOSITED CARBON RESISTORS

There is another type of carbon resistor known as the deposited carbon resistor. The carbon resistors that you will run into most frequently in electronic equipment can easily be identified because they are color coded by bands as shown in Fig. 10. The deposited carbon resistors are not made in the same way as these carbon resistors. They are made by depositing a layer of carbon on a form. The layer can be controlled closely and can be varied as necessary in order to make resistors that can be held to a very close tolerance. These resistors are usually made in tolerances of 1% and 1/2%. It is not likely that you will run into this type of resistor in commercial entertainment type equipment such as radio or TV receivers, but you will run into them in meters and test equipment where the accuracy of a meter reading will depend upon the accuracy of the resistors in the equipment. This type of resistor is identified by stamping the value of the resistor on the body of the resistor along with its tolerance. If you should have to repair a meter or some other test instrument and replace one of these resistors, it is important that the replacement have exactly the same resistance and tolerance as the original. Of course, if you have to replace a 100K-ohm, 1% resistor and can't get a 1% resistor, you can use a 1/2% tolerance resistor if one is available. 1/2% and 1% resistors are not nearly as readily available from radio and TV parts wholesalers as are the standard 5% and 10% molded carbon resistors. Often these precision resistors, as they are called, must be obtained by ordering them specially through your parts wholesaler.

SUMMARY

You have reached a point in your course now where you should be able to convert from ohms to K-ohms and megohms or from the larger units back to ohms without any trouble. The reason why it is important that you can convert from one unit to the other is that all three units are used by manufacturers on circuit diagrams and you have to know what is meant when any one of the units is used.

It is important for you to remember that resistors are made in only certain standard sizes and that all molded carbon resistors have certain tolerances. The standard tolerances are 5%, 10% and 20%. You will find mostly 10% resistors used in radio and TV receivers; both 10% and 5% resistors will be found in industrial control equipment.

You should start to learn the resistor color code by memory. You will have to use it over and over again to identify resistors in electronic equipment. However, as we point out don't try to memorize it all at once. Read it through two or three times whenever you think about it and you will soon have it memorized.

Remember that 1% and 1/2% resistors are used in test equipment and if you should have to replace any of these resistors be sure that you use an exact value replacement and a replacement having a tolerance of at least as close as the tolerance of the original.

Now answer the following self-test questions on this section of the lesson.

SELF-TEST QUESTIONS

(q) What is 4.7K-ohms equal to in ohms?

(r) Express .39 megohms in K-ohms and in ohms.

(s) What is 680,000-ohms in K-ohms and in megohms?

(t) A 2200-ohm, 10% resistor actually has a value of 2000 ohms. Is this resistor within its rated tolerance?

(u) A 10,000-ohm resistor has a tolerance of 5%. What is the maximum value resistance that the resistor might actually have and still be within tolerance?

(v) Reading from left to right the color bands on a resistor are orange, white, yellow and gold. What is the value and tolerance of the resistor?

(w) If a resistor is color coded brown, black, green and silver, what is its value and tolerance?

(x) If a resistor is color coded green, blue, orange and gold, what is its value and tolerance?

(y) A resistor is colored red, red, red and silver. What is its value and tolerance?

(z) In a certain piece of test equipment a 100K, 1% resistor has burned out. You have available a 100K, 1/2% resistor. Can you use this resistor as a replacement?

Resistors With Special Characteristics

We have already mentioned one of the important characteristics of carbon resistors, that is the fact that they change resistance with changes in temperature. Carbon itself has what we call a negative temperature coefficient. Most elements that carry electricity have a positive temperature characteristic. This means that if a copper wire is carrying a current and the temperature of the wire increases the resistance will increase - the wire has a positive temperature coefficient. Carbon, as an element, does the opposite - if it is heated, its resistance goes down; it has a negative temperature coefficient.

Most carbon resistors have a negative temperature coefficient. However, sometimes due to the way the resistor is made and due to the type of material used as a binder to hold the resistor together, the resistor might actually have a small positive temperature coefficient. What happens is that the carbon in the resistor has a negative temperature coefficient which tends to cause a resistance to go down with an increase in temperature but the other material has a positive temperature coefficient greater than the carbon temperature coefficient and this causes the resistance to go up when the temperature increases. With the two fighting each other, it is hard to predict what will happen. Some resistors will go down slightly in resistance when they are heated, others will increase slightly in resistance.

Wire-wound resistors and deposited-film resistors in general have a positive temperature coefficient. Their resistance will increase as the temperature is increased.

Actually, as far as a general purpose resistor is concerned, we would prefer to have them with a zero temperature coefficient. In other words, we would like their resistance to remain constant as their temperature changes. Changes in resistance due to temperature changes often produce undesirable results in electronic equipment. However, with modern manufacturing techniques, most carbon, deposited-film and wire-wound resistors have such a low temperature coefficient that any change in their temperature in normal operation will not cause their resistance to change sufficiently to cause any serious problem.

In some special applications, however, it is desirable to have a resistor whose resistance value will change with temperature. In this section of the lesson we are going to briefly study two of these devices.

THERMISTORS

A thermistor is a type of resistor that is made of a material whose resistance value varies with changes in temperature. The material used is a form of a semi-conductor material quite similar to the material used in the manufacture of transistors.

Thermistors have a negative temperature coefficient. This means that as the temperature increases, the resistance of the thermistor decreases. The amount that the resistance of the thermistor will change with a given change in temperature depends upon the type of material from which the thermistor is made.

Thermistors are quite often used in circuits where there is liable to be a large current surge when the equipment is first turned on. An example of this type of application is in the power supply of a television receiver that is designed for operation without a power transformer. When the equipment is first turned on, a very high surge current will flow for a short time. A thermistor placed in the circuit can limit this current to a safe value. As the equipment starts to operate, the current flowing through the thermistor causes it to heat so that its resistance value drops very rapidly and by the time the equipment has reached operating temperature and is ready to operate, the resistance of the thermistor has dropped to such a low value that it has very little effect upon the performance of the equipment. Thermistors of this type may have a resistance of 100 ohms or more when they are cold, and a resistance of only a few

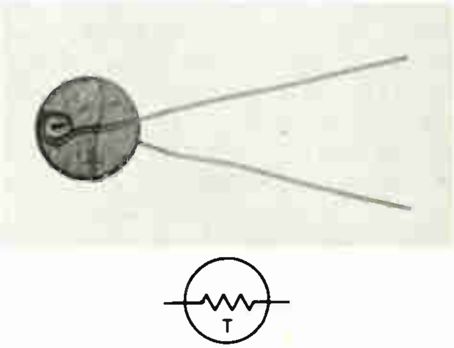


Fig. 12. A typical thermistor, such as might be found in a TV receiver, and its schematic symbol.

ohms when they have reached their normal operating temperature in the receiver.

A photograph of a thermistor such as you might find in the application we mentioned in the television receiver is shown in Fig. 12. Notice that the thermistor is made in the form of a round disc with leads attached to each side of it. The schematic symbol used to represent the thermistor is also shown in Fig. 12.

The thermistor type shown in Fig. 12 is the type you are most likely to encounter in TV receivers. However, there are many other different types. A photo of a number of different types is shown in Fig. 13.

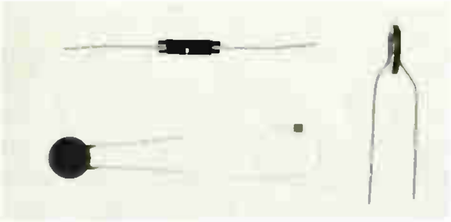


Fig. 13. Thermistors are made in many different shapes as shown above.

These types are often found in industrial electronic equipment. Sometimes they are used to control current surges, in other applications they are used to measure temperatures. You can tell the temperature of the thermistor by measuring its resistance and thus the thermistor can be used for temperature measuring applications.

VARISTORS

Another special type of resistor is the varistor. This resistor is also called a voltage-dependent resistor. This means that the resistance of the device depends upon the voltage across it. In other words, as the voltage across the varistor increases, the resistance of the varistor decreases.

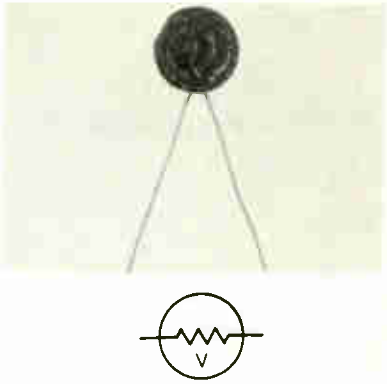


Fig. 14. A typical varistor and its schematic symbol.

Varistors are used in circuits to protect components from damaging high voltage transients. This could cause component failure. With a varistor in the circuit, as the voltage rises the resistance of the varistor decreases, drawing a large current from the voltage source which will lower the voltage.

Varistors will be found in some color TV receivers. A photo of a varistor is shown in Fig. 14 along with the schematic symbol used to identify it. You will notice that the varistor looks very much like a thermistor - as a matter of fact, it is sometimes difficult to tell them apart from their appearance alone.

HIGH-VOLTAGE RESISTORS

In some applications resistors will be used across circuits where there is a comparatively high voltage. Examples of this type of resistor will be found in many television receivers.

High-voltage resistors must be made quite long in order to keep the voltage from jumping across the resistor. Usually the resistance element is placed on a form in the shape of a spiral curve. An example of this type of resistor is shown in Fig. 15A. The resistor is about 2-1/2 inches long and is used in a circuit in a color TV receiver where the operating voltage is in excess of 6000 volts. The resistor is made by putting the carbon on a form shaped like a spiral that winds around the resistor from one end to the other as shown in the drawing in Fig. 15B.

Resistors of this type are made with a spiral type element because they normally have a very high resistance and by spiralling the resistance element around the form in this way it is possible to get a much longer path, and therefore the high resistance needed can be obtained in a reasonable size. The unit shown in the photograph has a resistance of 66 megohms. It would be difficult to get this much resistance in a resistor of this size and type by any method other than the spiral-wound method. If you should have occasion to replace a resistor of this type in a television receiver or in any other device where high voltages are used, you must be sure to use this special type of high-voltage resistor.

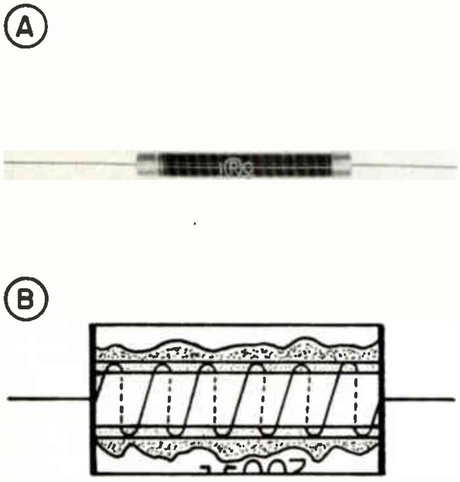


Fig. 15. A high-voltage resistor.

SUMMARY

In this section of the lesson we have briefly studied three special types of resistors - the thermistor, the varistor or voltage-dependent resistor, and the high-voltage resistor. A few years ago these three types of resistors were unknown to the electronics technician, but modern technology has developed these resistors and they are appearing more frequently in modern electronic equipment. Color TV in particular has brought these resistors into considerably more importance.

If you have to replace one of these resistors, you should try to obtain an exact duplicate replacement. Not only is the cold resistance of a thermistor or varistor important, but also the way that the resistance changes either with changes in temperature in the case of the thermistor or changes in voltages in the case of the varistor is important. The manner in which the resistance changes is usually of even more importance than the cold value of the part.

High-voltage resistors are used in circuits where the length of standard resistors is so short that if you tried to use one the voltage would simply arc across the resistor.

These resistors are usually made by the spiralled-carbon method so that a long path can be obtained in order to get a very high resistance.

SELF-TEST QUESTIONS

(aa) What is a thermistor?
(ab) Where are thermistors used?
(ac) Draw the schematic symbol for a thermistor.
(ad) What is a varistor?
(ae) Where are varistors used?
(af) How do you tell the difference between a thermistor and a varistor?
(ag) What is a high-voltage resistor?

Meters

We have already mentioned that resistors made with tolerances of 1% and 1/2% are used in electronic test equipment. Resistors made to these close tolerances are often called precision resistors. Precision resistors are used with meters in order to increase the usefulness of a given meter movement. Since this represents another important use of resistors, and since meters are very important, we are now going to present some of the basic fundamentals about meters.

The meter most frequently used in electronics for current, voltage and resistance measurements is the d'Arsonval* meter. The meter gets its name from the scientist who invented it.

Basically the d'Arsonval meter is a current-indicating device, but by arranging it in suitable circuits it can be used to measure voltage and resistance as well as current.

Let us go ahead and learn how the meter itself works and then we will see what changes we can make in the basic meter to make it more usable.

THE BASIC METER MOVEMENT

A simplified drawing of a d'Arsonval type meter is shown in Fig. 16. Notice that we have a permanent magnet and that the faces of the poles of the magnet have been curved. Between the poles of the magnet we have a coil that is wound on a very light frame. Usually the frame is made of a thin piece of aluminum.

The frame and coil are attached to light-weight pivots, and these pivots fit into jewel bearings. The bearings are securely supported by the meter frame so that the coil and the pivots are held in position and can rotate freely between the poles of the magnet. Attached to each pivot and anchored to the meter frame is a spring. There is a spring on each pivot and these springs are arranged to rotate the coil into approximately the position shown in the figure. Also attached to the pivot is a pointer as can be seen in the drawing. When

*Pronounced dar-son-val. The dar is like ar in car, son like son or sun, and the val like all in ball. d'Arsonval.

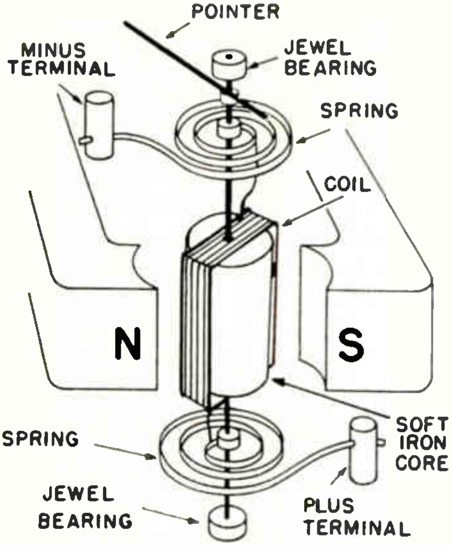


Fig. 16. How a d'Arsonval type of meter is made.

the coil rotates this pointer will rotate in a clockwise direction.

Notice that the ends of the coil are connected to the springs and the other ends of the springs are connected to terminals. One terminal is the negative terminal and the other terminal is the positive terminal.

When a current flows through the meter coil, the coil will become an electromagnet. If the current enters the negative terminal of the meter and leaves the positive terminal a field will be set up in the electromagnet that will be attracted by the field of the permanent magnet. The attraction between the two fields will produce a force called torque that will try to rotate the coil. The torque will cause the coil to rotate in a clockwise direction against the force or torque of the springs until the torque in the coil is balanced by the opposing torque of the springs. The higher the current flowing through the coil, the more torque is produced and the more the coil will be able to rotate against the opposing torque of the springs. As the coil rotates, the meter pointer moves in a clockwise direction and moves up the scale of the meter, indicating the current that is flowing through the coil.

A typical current scale is shown on the meter in Fig. 17. Notice that when the meter pointer moves all the way to the right side of the scale, the current flowing is 1 amp. We call this meter an ammeter because it measures the current in amps. We call it a 1 amp ammeter because a current of 1 amp gives a full scale deflection. If a current of 1/2 amp flows through the meter coil, only half as much torque, or rotating force will be developed, and as a result, the meter pointer will move only halfway up the scale. If the current flowing through the meter coil is one quarter of an amp, then one-fourth the torque needed to produce a full-scale deflection will be produced and the meter pointer will move only one-quarter of the way up the scale.

We mentioned earlier that the coil

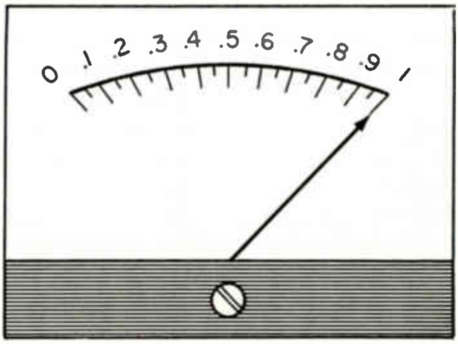


Fig. 17. A 1-amp ammeter.

was generally wound on a lightweight aluminum frame. The aluminum frame acts like a coil made of one turn of wire that is shorted. When a current flows through the meter coil and the coil begins to rotate, the one turn coil made up of the aluminum frame also rotates. As the aluminum frame rotates, it will cut through the field produced by the permanent magnet and a voltage will be induced in it. Although the voltage induced in the one turn coil made up of the frame will be low, a fairly high current will flow through the coil because it has a very low resistance. This in turn sets up a significantly strong magnetic field that opposes the motion of the meter coil. The net effect is that this opposition damps the movement of the coil. It prevents the coil from swinging too rapidly in a clockwise direction - this would cause the coil to swing past the position it is supposed to reach and oscillate back and forth around the position it should reach. The field produced by the current flowing in the aluminum frame will prevent this from happening and as a result the pointer will move upscale at a reasonable speed and indicate the value of current flowing with a minimum of oscillation back and forth past the correct value due to the coil rotating too rapidly when the current is first applied to it.

The d'Arsonval meter can be made very sensitive. By using a very lightweight frame and many turns of very fine wire to wind the coil and keeping the weight of the moving part of the meter as low as possible, it is possible to build a meter of this type that will indicate a current of 50 microamps quite easily. As a matter of fact, d'Arsonval meters that can indicate currents of only a few microamps can be made, but usually the most sensitive d'Arsonval meters used by technicians for routine measurements are 50 microampere meters. More sensitive meters are quite expensive and very delicate and are usually used in laboratory-type measurements rather than in the type of measurements that the service technician will normally make.

MEASURING CURRENT

To measure the current flowing in a circuit, the meter is placed in the circuit so that the current flowing in the circuit must flow through it. Fig. 18 shows how a meter can be connected in a simple series circuit to find the current flowing in the circuit. Notice the schematic symbol for the meter at B. The letter I, for current, may be placed inside of the circle as in the figure. Sometimes the letter A, meaning amperes, is placed in the circle and sometimes MA, meaning milliamperes, is used. µA is also used to indicate microamps.

Before you measure the current in a circuit, you need to have some idea of what the current might be. D'Arsonval meters are made in many different ranges. We already mentioned that this type of meter can be made very sensitive so that it can measure a current of only a few microamperes. If the meter is designed to measure currents in microamperes, it is called a microammeter. Some d'Arsonval meters have a scale on them that indicates the current in milliamperes. This type of meter is called a milliammeter. Still other meters are made to measure higher currents and the scale indicates the current in amperes; this type of meter is called an ammeter. All work on the same principle; they get their different names from the current values they are designed to measure.

If you should connect a microammeter in a circuit where the current flow is several amperes, the current flow through the meter would be so high that either you would burn out the meter coil or else the very strong current flowing through the coil would cause the coil to rotate so violently, that it would either bend the meter pointer by starting too fast or else slam the meter pointer up against the end of the scale and ruin the meter. Therefore, as we mentioned earlier you need to have some idea of what the current flow in the circuit is so you can be sure to use a meter that is capable of measuring the current flowing in the circuit. If you don't know what the current is, you should use the highest range meter you have. You can always put a more sensitive meter in the circuit later, if you find that the current is small and will not damage a more sensitive meter.

We mentioned that meters are available in many different ranges. Actually, meter manufacturers do not make a large number of different meter movements. Instead, they make a few standard meter movements and then extend the range of the meter by means of shunts.

You have already studied parallel circuits and you know that when two resistances are placed in parallel, part of the current will flow through one resistance and part through the other. The coil in a d'Arsonval meter has a certain resistance. For example, if you have a meter that indicates a current of 10 milliamperes and the coil has a resistance of 100 ohms, and if you place a 100-ohm resistor in parallel with the meter, half the current flowing in the circuit would flow through the meter

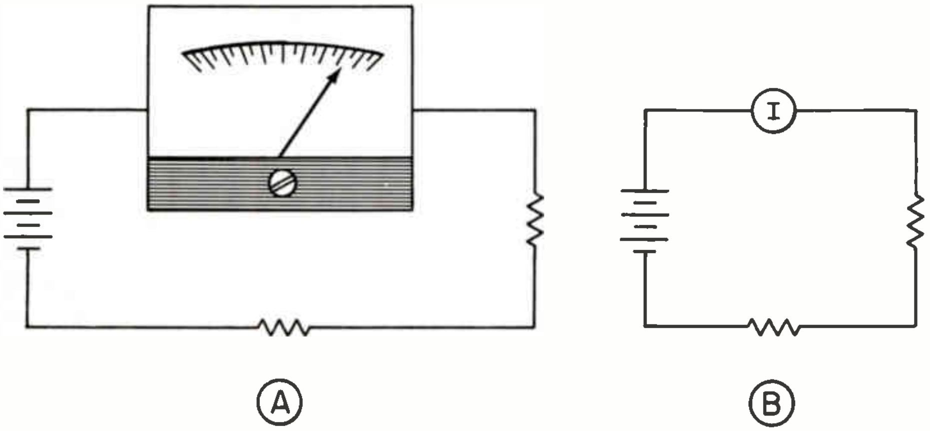


Fig. 18. A meter connected into a series circuit to measure current. Pictorial of meter is shown at A; schematic symbol, at B.

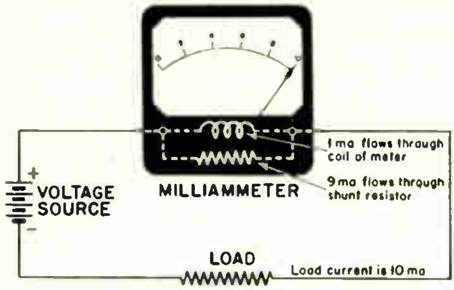


Fig. 19. By adding a shunt resistor, this 0-1 ma dc milliammeter can be made to read current up to 10 milliamperes.

coil and half through the resistance. In this case, if the total current is 10 milliamperes, only 5 milliamperes will flow through the meter coil. The remainder will flow through the shunt resistor. This means that the meter pointer would move only to half-scale.

An example of a meter used with a shunt is shown in Fig. 19. Here the basic meter movement is designed to give a full-scale deflection with a current of 1 milliampere through the coil. The meter has a resistance of 100 ohms. A shunt has been placed across the meter coil having one-ninth the resistance of the coil. Now, the current divides so that nine-tenths of the current will flow through the shunt and one-tenth through the coil. Therefore, it is possible to place a scale on the meter that indicates 10 milliamperes at full scale. When the total current flowing is 10 milliamperes, 1 will flow through the coil and cause the meter to read full scale and 9 will flow through the shunt.

Manufacturers use shunts to provide a large number of meters with different ranges. The chances are if you buy a 50 ma meter and a 500 ma meter, they will both be either 5 ma or 1 ma meters with suitable shunts inside the meter to give the higher ranges.

DC VOLTMETERS

A d'Arsonval meter can be used to read voltages by connecting a resistor in series with the meter. This resistor is called a multiplier. In Fig. 20 we have shown how a d'Arsonval meter can be used with a multiplier to measure voltage. The basic meter is a 1 milliampere meter. This means that at full scale the meter will indicate a current of 1 milliampere. Now, you know from Ohm's Law that when a voltage is applied to a resistance a current will flow through the resistance and the value of the current will depend upon the voltage and on the resistance. If we put enough resistance in series with the meter so that the total resistance is 1000 ohms, then it will take a voltage of 1 volt to cause a current of 1 ma to flow through the resistance and the meter. If we connected the combination across a bat-

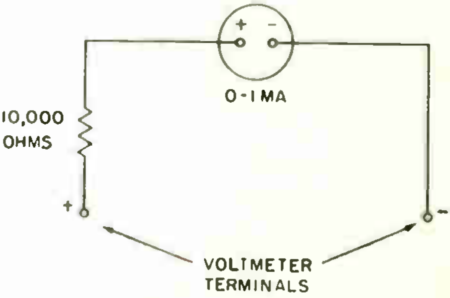


Fig. 20. A dc voltmeter made from a 0-1 ma dc milliammeter and a 10,000-ohm resistor.

tery and the battery voltage was 1 volt, a 1 milliampere current would flow and the meter pointer would indicate full scale. If the voltage was only 1/2 volt, then only half a milliampere would flow in the circuit and the meter pointer would move up to half scale.

If instead of a 1000-ohm resistance we add enough resistance in series with the meter to give us a total resistance of 10,000 ohms, then it would take 10 volts to cause a current of 1 milliampere to flow in the circuit. Under these conditions the meter pointer would again move up to full scale.

With a multiplier in series with the meter we can calibrate the meter directly in volts rather than in milliamperes. With a total resistance of 10,000 ohms in the circuit we can mark the full scale reading as 10 volts and half scale reading as 5 volts and so on. If the total resistance in the circuit is 100,000 ohms then a full scale reading would be 100 volts.

Notice that for each volt we have added a resistance of 1000 ohms in series with the meter. If we want the meter to read 1 volt full scale then we need a total resistance of 1000 ohms. If we want the meter to read 10 volts full scale then we need a total resistance of 10,000 ohms and if we want the meter to read 100 volts full scale then we need a total resistance of 100,000 ohms. We call this type of meter a 1000-ohms per volt meter. We say that the meter sensitivity is 1000 ohms per volt. You will see later that the sensitivity of the meter is important in taking voltage measurements.

The meter we have been discussing so far has been a 1 milliampere meter. However, if instead of using a 1 milliampere meter as a voltmeter we start with a basic meter movement of 50 microamperes we will have a much more sensitive meter. If we convert a 50 u amp meter to a voltmeter when the meter pointer reads full scale, it means that the current flowing through the meter and its multiplier is 50 microamperes. If we want to build a meter that will indicate full scale when a voltage of 1 volt is applied to it, we can use Ohm's Law to find out how much resistance we need in the circuit. Using

$$R = \frac{E}{I}$$

and substituting 1 volt for E and 50 microamperes for I we get

$$R = \frac{1}{.000050}$$

and we can multiply by 1,000,000 to convert this current to amperes and then we will have

$$R = \frac{1 \times 1{,}000{,}000}{50}$$

$$R = \frac{1{,}000{,}000}{50}$$

and now cancelling one zero above and below the line, and dividing 5 into 100,000 we find that

$$R = 20{,}000 \text{ ohms}$$

We say that the sensitivity of this meter is 20,000 ohms per volt. If instead of a 1-volt meter we want a 10-volt meter we need to add ten times as much resistance or a total of 200,000 ohms. If we want a 100-volt meter then we would have to add 100 × 20,000 or 2,000,000 ohms in series with the meter.

Since the higher sensitivity meter actually draws less current from the circuit, the meter will have less tendency to upset the circuit when voltage measurements are taken. This is particularly important in electronic circuits where the resistance is high. If you use a 1,000-ohm per volt meter to take a voltage measurement, the chances are that the meter itself will take more current than is actually being used to operate the circuit. This means that the meter will upset the circuit so that the voltage reading you will obtain will not be the actual voltage that is present in the circuit when the meter is disconnected. On the other hand, a 20,000-ohm per volt meter has twenty times the resistance; it takes far less current from the circuit and is much less likely to upset the voltages in the circuit.

OHMMETERS

An ohmmeter is a device used to measure resistance. Actually, an ohmmeter is nothing more than a d'Arsonval type meter used in conjunction with a battery and a series resistor. A circuit of a typical ohmmeter is shown in Fig. 21.

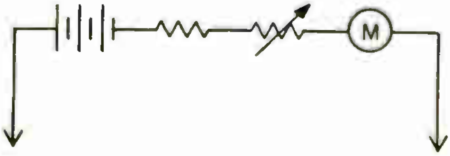


Fig. 21. A schematic diagram of an ohmmeter.

As you can see in the circuit the ohmmeter consists of a 4.5 volt battery, two resistors (one a fixed resistor and the other a variable resistor), and a 1 ma meter. The fixed resistor has a resistance of 4000 ohms. The adjustable resistor has a resistance of 1000 ohms and under normal circumstances you would short the test probes of the ohmmeter together and then adjust the variable resistor to get a full scale reading. If the battery voltage is exactly 4.5 volts, you will get a full scale reading, in other words, a current of 1 ma through the meter when the resistance of the potentiometer is set at slightly less than 500 ohms. With this setting of the potentiometer you will have a total resistance in the circuit of 4500 ohms. The potentiometer is set at a value slightly less than 500 ohms to make up for the internal resistance of the battery and the resistance of the meter. In any case, with a voltage of exactly 4.5 volts, the resistance in the circuit will be 4500 ohms.

Now if you separate the test probes, the circuit will be open and the meter pointer will drop back to 0. If you place a 4500-ohm resistor between the test probes, then the total resistance in the circuit will be 9000 ohms, and the current that will flow in the circuit will be .5 ma. In other words, you will get a half-scale deflection on the meter. If you were measuring the resistance of an unknown value and you got a half-scale reading, you would know immediately that its resistance was 4500 ohms.

As a matter of fact, you can take any current reading that you might get on the meter scale and use Ohm's

Law to calculate the total resistance in the circuit. Knowing that the battery voltage is 4.5 volts, you simply use the formula

$$R = \frac{E}{I}$$

and substitute 4.5 volts for the battery voltage and the value of current indicated on the meter. This will give you the total resistance in the circuit. From this value you subtract 4500 ohms, which is the fixed resistance in the circuit and this will give you the resistance of the unknown resistor.

Instead of going through this procedure of calculating the resistance value each time you make a measurement, these calculations can be worked for various current values and the meter calibrated directly in ohms. This is what is done in an ohmmeter.

If you need to measure higher resistances, you can use a higher battery voltage. For example, if you used a 45-volt battery then you have to put a total of 45,000 ohms in the circuit to get a full-scale meter reading. Then a center scale reading would represent a resistance of 45,000 ohms, instead of 4500 ohms as before.

Another way of building a meter that will give higher resistance readings conveniently is to use a more sensitive meter. If you use a 50 microamp meter, you will need a total resistance in the circuit of 90,000 ohms to give you a full-scale reading. Thus with this type of meter, a center scale reading will indicate a resistance of 90,000 ohms.

MULTIMETERS

A multimeter is simply a meter in which a single d'Arsonval type meter is arranged with a series of switches, resistors and batteries, so that by rotating the switches it can be used to perform a large number of functions. One switch is usually called the function switch. By putting this switch in the correct position, you can use the meter either to measure voltage, current or resistance. The other important switch on the multimeter is called the range switch. This switch controls the full-scale reading that you will obtain on the meter. In other words, with the switch in one position, when you are measuring voltage, a full-scale reading might indicate 10 volts. With the switch in another position the full-scale reading might indicate a voltage of 100 volts, and in a third position it might indicate a voltage of 500 volts.

Multimeters are widely used by service technicians because the basic d'Arsonval meter movement is quite expensive, and it is more economical to use a single meter with suitable switches and resistors to perform all types of measurements than it is to have a number of separate meters for different measurements.

SUMMARY

As an electronics technician, you will not have to know how meters are designed or built. You should understand the basic operation of a meter so that you will know how it works - this will help you use it to the best advantage. You must know that meters are very delicate and must be handled carefully. If you drop a meter or bang it hard you are liable to knock the pivots out of the jewel bearings, in which case the meter pointer will stick as it moves upscale.

You must avoid overloading a meter. The coiled springs in a meter are made of phosphor bronze. If they are overloaded they overheat and their shape is distorted. If adjacent turns of a spring touch enough, friction is produced to upset the meter accuracy.

Technicians seldom have to take current measurements, but you should know how to connect a meter in order to take a current measurement. You must remember to use a meter that is capable of measuring the current in a circuit. If you have no idea what the current is you should start with the largest meter you have first and then work down to a smaller range meter after you are sure that the current is low enough not to damage it.

Voltage measurements are probably the most important measurement to the technician. You need to know how to take a voltage measurement and you need to understand what effect the meter sensitivity will have on the accuracy of the voltage measurement. A meter with high sensitivity will take less current from the circuit and there will be less chance of the meter upsetting the circuit so that you will obtain an erroneous voltage measurement.

When you start working on your kits, you will use your meter to take both current and voltage measurements. You will learn how to read the scale on the meter - we will not go into it in this lesson because it will be much easier to learn to read the scale when you actually have the meter in front of you.

SELF-TEST QUESTIONS

(ah) What is the name given to the basic meter movement most frequently used in voltage, current and resistance measurements?

(ai) What causes the pointer of a meter to move upscale when a current flows through the meter?

(aj) What force must the coil in a meter overcome before it can rotate?

(ak) What purpose, other than to hold the coil, does the aluminum frame on which the coil is wound serve?

(al) How is a meter connected to measure current flowing in a circuit?

(am) How do you connect a voltmeter in order to measure the voltage across a part?

(an) Which type of voltmeter will upset the circuit performance less, a 1000-ohm-per-volt meter or a 10,000-ohm-per volt meter?

ANSWERS TO SELF-TEST QUESTIONS

(a) A series-dropping resistor drops the available voltage to the value required by the load.

(b) 38 volts. The two 35-volt tubes will require a total voltage of 70 volts in series, and the two 6-volt tubes will require an additional 12 volts, giving a total required voltage of 82 volts. Subtracting 82 volts from the 120-volt power line gives us a voltage of 38 volts which the series-dropping resistor must drop.

(c) 126.6 ohms. Using Ohm's Law to find the value resistor we have a voltage of 38 volts and a current of .3 amps. Using the formula

$$R = \frac{E}{I}$$

and substituting the values for current and voltage we get

$$R = \frac{38}{.3} = 126.6 \text{ ohms}$$

Since it would be impossible to obtain a resistor of this value you use the nearest standard size which is 130 ohms. If you get 126 or 127 ohms as your answer your answer is close enough; when you went to buy a resistor you would simply have to take a resistor having a resistance as close as you could get to the calculated value.

(d) A bleeder is used to regulate or help maintain constant the voltage across a load.

(e) A bleeder that draws a substantial current will be more effective than a high-resistance bleeder that draws only a small current. The greater the bleeder current in proportion to the load current, the more effective the bleeder will be insofar as regulating the load voltage is concerned.

(f) The current consumed by the bleeder is wasted current insofar as performing any other useful function other than regulating the voltage across the load is concerned. Since the more current you draw from a power supply, the larger the components (hence the more expensive they must be), the bleeder current should be no larger than necessary to give you the regulation required. Excessive bleeder current with regulation better than is required is costly and can run the cost of the power supply substantially higher than necessary.

(g) 10K ohms. You can determine the resistance of the series-dropping resistor two ways. The easy way: if you notice that the voltage across the load is 200 volts and you have to drop 100 volts across the dropping resistor, you can see that the resistance of the dropping resistor must be half the resistance of the load. The other way is to calculate the current through the load resistor using Ohm's Law. Once you have the current you can then calculate the size resistor required as the series-dropping resistor to drop 100 volts. From Ohm's Law the current through the load will be

$$\frac{200}{20{,}000} = .01 \text{ amps}$$

Now to find the value of the dropping resistor you have to use the formula

$$R = \frac{E}{I}$$

$$= \frac{100}{.01} = 10K \text{ ohms.}$$

(h) The watt.

(i) 45 watts. You use the formula

$$P = E \times I$$

and substituting 15 for E and 3 for I we get

$$P = 15 \times 3 = 45 \text{ watts.}$$

(j) When we say a resistor is dissipating 10 watts, we mean that the resistor is using 10 watts of electrical energy. We say it is dissipating the power because it changes the power from electrical energy to heat. It is taking 10 watts of electrical energy out of the circuit and converting it to heat.

(k) 10 watts. To find the power dissipated by the resistor we use the formula

$$P = \frac{E^2}{R}$$

Remember that $E^2 = E \times E$. Substituting 100 for E and 1000 for R we have

$$P = \frac{100 \times 100}{1000}$$

and cancelling three zeros above the line and three zeros below the line we have:

$$P = 10 \text{ watts.}$$

(l) 1/2 watt. Again, to solve this problem we use the formula:

$$P = \frac{E^2}{R}$$

Substituting 50 volts for E and 5000 ohms for R we have

$$P = \frac{50 \times 50}{5000} = \frac{2500}{5000} = 1/2 \text{ watt.}$$

(m) 100 watts. To solve this problem we use the formula

$$P = I^2R$$

substituting 2 for I and 25 for R we have

$$P = 2 \times 2 \times 25 = 100 \text{ watts.}$$

(n) 10 watts. To solve this problem we must convert milliamps to amps and K-ohms to ohms and then use the formula

$$P = I^2R$$

10 ma = .01 amps.
100K = 100,000 ohms.

Substituting these values in the formula we get

$$P = .01 \times .01 \times 100{,}000$$
$$P = .0001 \times 100{,}000.$$

To multiply 100,000 by .0001 we simply move the decimal point four places to the left thus

$$P = 100{,}000 \times .0001 = 10 \text{ watts.}$$

(o) 3 ohms. Maximum power transfer will be obtained when the load resistance is equal to the battery resistance.

(p) You would use a 10-ohm resistor to get maximum power transfer to the load; resistance should equal the battery resistance. With a 10-ohm load resistance, the total resistance in the circuit will be 20 ohms, and therefore the current flow in the circuit will be

$$I = \frac{20}{20} = 1 \text{ amp.}$$

The total power produced by the battery will be

$$P = E \times I$$
$$P = 20 \times 1 = 20 \text{ watts.}$$

The power transferred to the resistor can be found using the formula

$$P = I^2R$$
$$P = 1 \times 10 = 10 \text{ watts.}$$

(q) 4700 ohms.

(r) .39 megohms equals 390K-ohms; .39 megohms is also equal to 390,000 ohms.

(s) 680,000 ohms equals 680K equals .68 megs.

(t) The resistor is within its rated tolerance. A 2200-ohm resistor with a tolerance of 10% may vary as much as 220 ohms above or below its indicated value. Subtracting 220 from 2200 gives us 1980 as the lower limit of the resistor. Since 2000 ohms is between this lower limit and the indicated value of the resistor, the resistor is within tolerance.

(u) 10,500 ohms. 5% of 10,000 ohms is 500 ohms. Therefore the maximum value that the resistor can have and still be within tolerance will be 10,000 plus 500 equals 10,500 ohms.

(v) 390,000 ohms, which is also equal to 390K-ohms. The tolerance is 5%.

(w) 1,000,000 ohms or 1 megohm. The tolerance is 10%.

(x) 56,000 ohms or 56K-ohms. The tolerance is 5%.

(y) 2200 ohms or 2.2K-ohms. Its tolerance is 10%.

(z) Yes. The 1/2% resistor has a closer tolerance than the 1% resistor. This means that it will vary less from the indicated value than the 1% resistor - in other words it is a better resistor. You can always use a better resistor - one with a closer tolerance as a replacement.

(aa) A thermistor is a special resistor with a negative temperature coefficient. In other words, as the resistor heats, its resistance will decrease.

(ab) Thermistors are used in circuits in which high current surges are often obtained when the equipment is first turned on. The high cold resistance of the thermistor limits the initial current surge. As the thermistor heats up, the resistance drops so that it has very little effect on the circuit performance.

(ac) See Fig. 12.

(ad) A varistor is a voltage-dependent resistor. A voltage-dependent resistor is a resistor whose resistance depends upon the voltage applied across it. If the voltage increases, the resistance of the varistor decreases.

(ae) Varistors are used in circuits where sudden increases of voltage could damage components or otherwise upset the performance of the circuit. With a varistor in the circuit, as the voltage increases, the resistance of the varistor decreases, drawing a large current from the voltage source. The increased current drain tends to lower the voltage to a safe level.

(af) Often you cannot tell the difference between a thermistor and a varistor simply by looking at them. You should refer to the schematic diagram of the equipment in which they are used to identify each type.

(ag) A high-voltage resistor is a resistor made for use in high voltage circuits. The resistor is longer than most resistors in order to prevent a voltage arc across the resistor. High-voltage resistors are usually made by the spiral-wound carbon technique in order to provide a carbon path long enough to produce the required resistance.

(ah) The d'Arsonval meter.

(ai) The current flowing through the meter coil sets up a magnetic field. This field working with the magnetic field of the permanent magnet in the meter produces a torque which causes the coil and its frame to rotate. The meter pointer is attached to the coil frame and so the meter pointer moves upscale.

(aj) The opposing torque of the springs. The springs are used to hold the meter coil and pointer in a 0 position when no current flows through the coil, and to oppose the movement of the coil when current flows through the coil.

(ak) The aluminum frame acts as a shorted turn. The motion of the coil in the magnetic field of the permanent magnet induces a voltage in the coil which opposes the movement of the coil and frame. This tends to damp the coil movement and prevent its oscillating or swinging back and forth past the indicated value.

(al) The meter is connected in series with the circuit to measure current flowing in the circuit.

(am) You connect the voltmeter directly across the part where you want to measure the voltage. The voltmeter must be connected with the proper polarity; the negative side of the meter must be connected to the end of the part that is connected closest to the negative terminal of the voltage source, and the positive terminal must be connected to the end of the part closest to the positive terminal of the voltage source.

(an) A 10,000-ohm-per-volt meter will have less effect on the circuit because it will take less current from the circuit when you take a voltage measurement.

Lesson Questions

Be sure to number your Answer Sheet B105-1.

Place your Student Number on every Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable. However, don't hold your answers too long; you may lose them. Don't hold answers to more than two sets at a time or you may run out of lessons before new ones can reach you.

1. Name three important kinds of wire-wound resistors.

2. What is a series-voltage-dropping resistor?

3. A 750-ohm load must be operated with a voltage of 75 volts. The output voltage from the power supply is 125 volts. What value of series-dropping resistor should be used to drop the power supply voltage to the correct value for the load?

4. A 15-volt battery is supplying a current of 3 amps to a load. What is the power the battery is supplying?

5. The voltage across a 5000-ohm resistor is 100 volts. How much power is the resistor dissipating?

6. What is the purpose of a bleeder?

7. What is a thermistor?

8. Express the following resistance values in ohms:
   (a) 2.2K, (b) 470K, (c) 3.3 megs, (d) .17 megs. (e) .47 megs.

9. An ammeter has a full scale reading of 1 amp and an internal resistance of 1 ohm. A separate external 1-ohm shunt is connected in parallel with the meter. If the meter and shunt are connected into a circuit, and the meter indicates a current of .5 amps, what current is actually flowing in the circuit?

10. What do we mean when we say that a meter has a sensitivity of 1000 ohms per volt?

A PLAN FOR YOUR FUTURE

In a radio interview a few minutes after a championship heavyweight boxing match, one of the fighters stated his plans for the future as follows:

> "I'm going to get myself in shape, fight my own fights, and listen to nobody!"

You can use these dynamite-packed words as your plan for the future, too. Here's the way:

"GET MYSELF IN SHAPE." You're doing this right now, because the NRI Course gets you in shape for a career in electronics. But remember that it takes the complete NRI Course, with all its associated practical work, to get you completely in shape.

"FIGHT MY OWN FIGHTS." In real life, the only person who can bring you success is YOU yourself. Expecting somebody else to do your work and fight for your success is just wishful thinking.

"LISTEN TO NOBODY." Even friends and relatives will at times ridicule your studies -- they can't help it, because seeing you get ahead makes them feel uncomfortable about their own laziness. So, remember human nature, and don't give anyone a chance to discourage you.

J. F. Thompson

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ACHIEVEMENT THROUGH ELECTRONICS

nri

HOW COILS ARE USED

B106

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HOW COILS ARE USED

B106

STUDY SCHEDULE

By dividing your study into the steps given below, you can get the most out of this part of your NRI Course in the shortest possible time. Check off each step when you finish it.

☐ 1. **Introduction** .... **Pages 1 - 3**
Here we describe how coils are used, different types of coils, and basic coil action.

☐ 2. **Magnetic Circuits** .... **Pages 4 - 9**
Similarities between magnetic circuits and electrical circuits are brought out.

☐ 3. **Using Coils to Produce Voltage** .... **Pages 10 - 16**
You learn how flux linkages can be changed to produce voltage, and you study Lenz's Law of coils.

☐ 4. **Inductance** .... **Pages 16 - 23**
We take up the basic property of coils and learn about self-induced voltages and mutual inductance.

☐ 5. **Ohm's Law for Coils** .... **Pages 24 - 36**
You learn how to find the current in an ac circuit by using vectors or mathematics and you also study Kirchhoff's Voltage Law, the importance of phase and what the Q of a coil is.

☐ 6. **Answers to Self-Test Questions** .... **Pages 36 - 40**

☐ 7. **Answer the Lesson Questions.**

☐ 8. **Start Studying the Next Lesson.**

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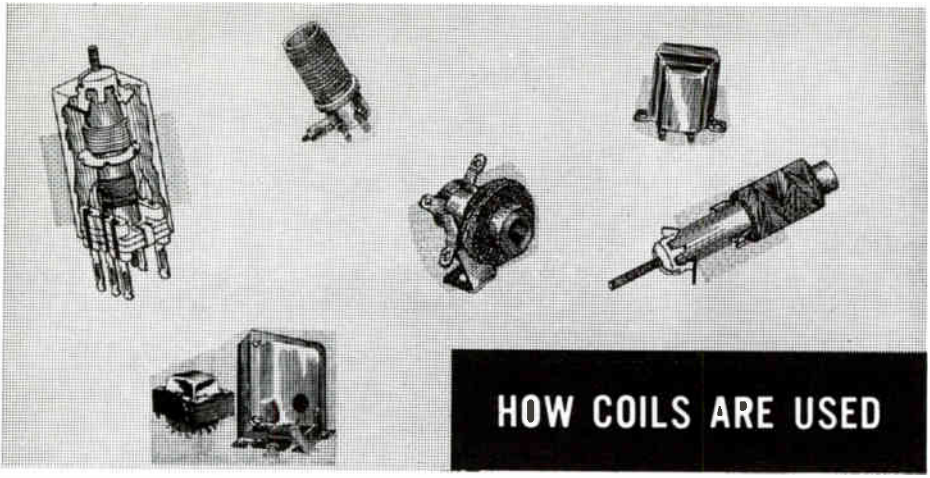


HOW COILS ARE USED

Coils are important to the electronics technician because they are used in all types of electronic equipment. They are used in many different ways to perform different jobs. Many different types of coils are used in electronic equipment - some coils may have only one or two turns whereas other coils may have several thousand turns. You will find all types of coils in industrial electronic equipment, in radio and television receivers, and for that matter, in practically every type of electronic equipment you will encounter. Since you will find coils used in all types of electronic equipment, it is important for you to understand what they are used for and how they work.

HOW COILS ARE USED

During the daytime you can probably find somewhere between ten and twenty-five different stations operating on the standard broadcast band on your radio receiver. During the evening hours you can probably find even more stations coming in. Coils are used with capacitors in special circuits called resonant circuits to enable you to select one signal and reject the signals from the other radio stations. Similarly, coils are used in television receivers to enable you to tune from one channel to another. The coils used for this purpose in radio receivers will have many turns on them whereas the coils used to select the different channels in a TV receiver will have only a few turns on them.

Coils are used in power supplies to help smooth the pulsating dc output from a rectifier to pure dc. Coils used for this purpose are called filter chokes or simply chokes. They act to permit direct current to flow through them without any opposition, but offer a high opposition to ac current or any change in the amplitude of the direct current.

Coils are used to produce motion. You have already seen an example of this in the d'Arsonval meter. The current flowing through the coil produces a magnetic field which acts with the field from the permanent magnet to cause the coil to rotate. Coils are used in motors in much the same way; the magnetic field produced in a coil wound on a form called an armature opposes or attracts the field produced by a stationary magnet and the armature rotates. Coils are also used in generators to produce electricity; rotating the coil so that the turns of the coil cut through the magnetic lines of force produced by the field or stationary magnet of the generator results in a voltage being induced in the turns of the coil.

Coils are used in transformers. You already know that a transformer is nothing more than two or more coils wound on a common core. If ac is fed to one of the coils, which we call the primary coil, a voltage will be induced in the other coil, which we call the secondary coil. If the secondary coil has more turns on it than the primary coil, the total voltage produced by the secondary coil will be higher than the primary voltage, but if the secondary coil has fewer turns on it than the primary coil, the voltage produced by the secondary winding will be lower than the voltage applied to the primary coil.

TYPES OF COILS

We have already mentioned that a coil used to select the various channels in a TV receiver may have only a few turns. In fact, a coil used in a UHF TV tuner is often made with a wire shaped something like a ribbon rather than a round piece of wire. The material is usually silver plated to cut down losses and the total coil will consist of about three quarters of a turn with a diameter of about an inch and a half. On the other hand, in a long wave receiver (a receiver designed to receive stations lower in frequency than the standard radio broadcast band) you may find coils wound on a form about an inch in diameter and having close to one thousand turns. Both coils perform the same task - they are used along with capacitors to select one radio frequency signal and reject others.

We mentioned that choke coils were used in power supplies to help provide smooth dc. A choke coil of this type found in a typical color TV receiver will be wound on an iron core. The coil itself will usually have several hundred turns and the complete assembly may weigh two or three pounds. On the other hand, the choke coil used for the same purpose in a large radio transmitter will be much larger. The iron core itself will be much larger and a much larger size of wire will be used because the wire will have to carry a heavier current. Chokes of this type will weigh one hundred pounds or more.

You will also run into small chokes called radio frequency chokes (abbreviated rfc). A radio frequency choke may have only a few turns and may be completely self-supporting or it may have several hundred turns and be wound on some nonmagnetic type of material. The number of turns required on a radio frequency choke depends on the frequency at which the choke is to be used and how much opposition it must offer to the flow of radio frequency currents through it. Generally speaking, the higher the frequency at which the choke is to be used, the fewer the number of turns the choke will have.

In spite of the great difference in the size of the coils we have described, their operation is basically the same. Thus it is important for you to understand the basic facts about how a coil works. Once you have learned these facts you will know exactly what a coil does in the circuit whether it is a small coil having two or three turns or a large coil with many turns wound on an iron core.

COIL ACTION

In its simplest form a coil is nothing more than one or two turns or loops of wire, usually wound in a circular or helical (spiral) shape. If the coil is self-supporting so that it has no core other than air, it is called an air-core coil. If the coil is wound on a cardboard, ceramic, or non-magnetic type of material, it is also called an air-core coil. The cardboard form or ceramic form are used only to hold the turns of wire in place, and have no appreciable effect on the performance of the coil. On the other hand, if the coil is wound on a form made up of a magnetic type of material such as iron, it is called an iron-core coil. Air-core coils are frequently placed inside metal shields or housings to prevent their picking up interference from outside sources or producing interference in other circuits. These shields may have some effect on the performance of the coils, but it is quite different from the effect of an iron-core and so they are still considered as air-core coils.

You already know that when a current is flowing through a wire there is a magnetic field around the wire as shown in Fig. 1A. The current produces magnetic lines of force, which are also known as magnetic flux or flux lines. When the wire is bent into a loop as shown in Fig. 1B, the magnetic lines of force all go through the loop in the same direction. This concentrates the magnetic flux around the loop. If, instead of being bent into a single loop, the wire is bent into a number of loops so that the coil has a number of turns, additional magnetic flux will be created, which will result in a stronger magnetic field.

Because of the magnetic flux, the coil offers more opposition to the flow of alternating current than it does to the flow of direct current. You will see in this lesson why this is so. Once you understand why a coil offers more opposition to ac than to dc, you will have a good understanding of how a coil works.

Since the operation of a coil depends upon the magnetic flux produced by the coil, it is important that you know more about magnetic circuits. Therefore, before going ahead with our study of coils, we will study magnetic circuits.

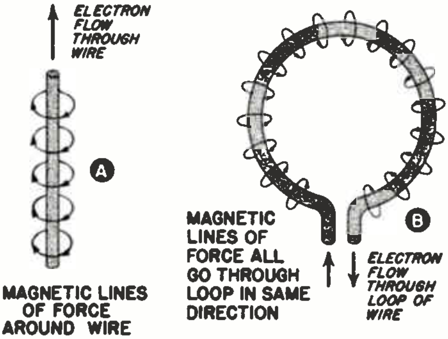


Fig. 1. When current flows through a wire, magnetic lines of force are set up around the wire as at A. When the wire is bent into a loop, the lines of force all go through the loop in the same direction, as shown at B.

Magnetic Circuits

You already know that the magnetic lines of force produced by a current flowing through a coil exist only as long as current flows. Once the current flowing through the coil stops, the magnetic lines of force will disappear.

Another important fact is that the magnetic lines of force are complete loops, having no ends. Notice that in Fig. 1, the magnetic lines of force around the wire and around the single coil were represented as complete loops. When two turns of wire are placed close together, the magnetic lines of force form complete loops around the two turns as shown in Fig. 2. Fig. 3 shows a coil made up of a number of turns and shows how the lines of force come out of the left of the coil and circle around to the right end of the coil. Notice that all of the lines of force are actually complete loops. We have not tried to draw all the magnetic lines of force that exist around the coil having a current flow through it. The coil may have thousands of such magnetic lines each forming a complete loop and passing through all or part of the coil and radiating out from the ends of the coil. The path of these magnetic lines of force is the magnetic circle of the coil. Although most of the lines of force will be concentrated near the coil, some will extend quite some distance from it.

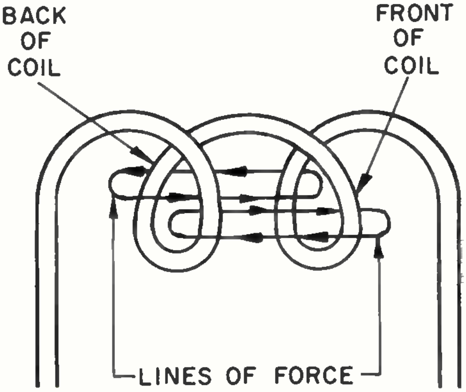


Fig. 2. Lines of force loop around both turns of the coil.

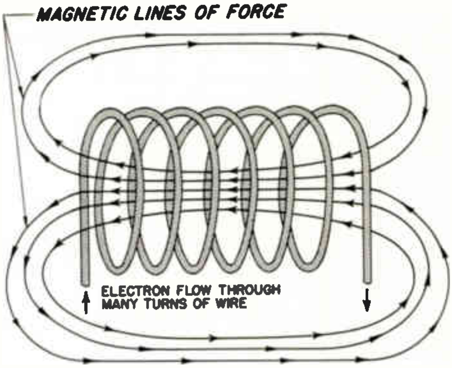


Fig. 3. When current flows through a coil, magnetic lines of force are produced. These are complete loops, passing through and around the coil.

AIR-CORE COILS

As we mentioned previously, some coils are completely self-supporting or wound on a cardboard or ceramic form. The purpose of these forms is simply to support the turns of wire making up the coil. Cardboard or ceramic serves no useful purpose as far as the operation of the coil is concerned. The actual core of the coil is simply air. This means that the lines of force must travel through air. This is the basic definition of an air-core coil: it is a coil in which the lines of force must travel through air or some other material that acts just like air insofar as the magnetic lines of force are concerned.

IRON-CORE COILS

Frequently a coil is wound on an iron or steel form or on a cardboard form with an iron or steel slug inside it. The iron or steel core makes a better magnetic circuit than air, and there will be a greater number and concentration of the magnetic lines of force. This means there will be more flux lines produced by the coil. This type of coil is called an iron-core coil. In coils designed for use in a power line or at audio frequencies, the iron-core is made up of thin strips of iron or steel called "laminations." These pieces of steel are fitted together to make a core, as shown in Fig. 4. As you can see, the core actually surrounds the coil and goes through the center as well. Fig. 5 shows how such a coil is constructed. This type of construction is used rather than a solid iron or steel core because it is more efficient. You will learn more about this in a later lesson.

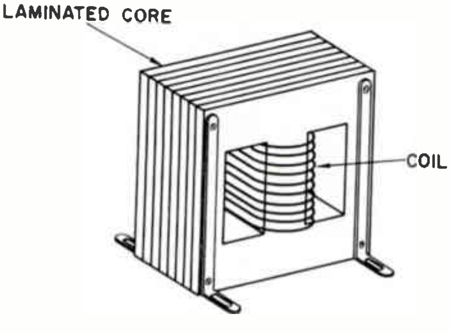


Fig. 4. Iron cores are frequently made of thin sheets of metal bolted together.

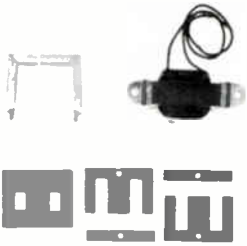


Fig. 5. Construction of an iron-core coil with laminated core.

In high-frequency circuits a powdered iron core is often used. This type of core is made by pulverizing iron filings and mixing them with a binder to hold them together and to insulate the particles from each other. A core of this type, called a slug, is often inserted in a coil by means of a screw so it can be adjusted in and out of the coil. This type of coil is shown in Fig. 6. The schematic symbol is shown beside it. Two or three lines drawn beside a coil indicate that it has an iron core, and the arrow indicates that it is movable. A coil with this type of core is called a slug-tuned coil.

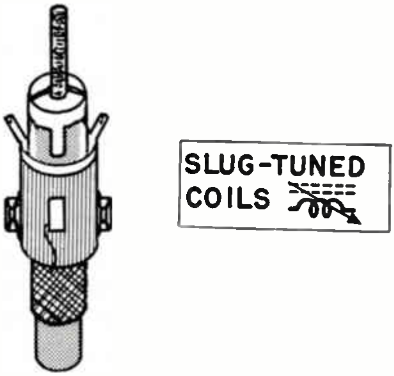


Fig. 6. A slug-tuned coil and its schematic symbol.

MAGNETOMOTIVE FORCE

The force that sends current around an electric circuit is called an electromotive force or voltage. The force that sends magnetic flux around a magnetic circuit is called magnetomotive force. It exists in every current-carrying coil.

The unit of magnetomotive force is the ampere-turn. If a coil has one turn and the current flowing through it is 1 amp, the magnetomotive force is 1 ampere-turn. If the coil has 10 turns and the current flowing is 1 amp, the magnetomotive force is the product of the two, or 10 ampere-turns. If a coil has 5 turns, and the current flowing through it is 5 amperes, the magnetomotive force is 25 ampere-turns. Thus, to find the magnetomotive force in a coil, you simply multiply the current flowing through it in amperes by the number of turns on the coil. You can increase the magnetomotive force of the coil by increasing the current flowing through the coil or by adding more turns to the coil and keeping the current constant.

As an electronics technician it is very unlikely that you will ever have to calculate the magnetomotive force produced by a coil in a circuit. However, you should know what it is. It is essential to understand magnetic circuits in order to understand magnetic devices.

RELUCTANCE

You already know that every electric circuit has resistance. Resistance is the opposition to current flow in the circuit. Just as there is opposition to current flow in an electric circuit so also is there opposition to flux in a magnetic circuit. This opposition to flux is called reluctance.

The reluctance in a magnetic circuit is distributed along the entire path taken by the flux. In other words, there is reluctance all the way around the path followed by each magnetic line of force both in the core and in the air. We can actually make a very close comparison between a magnetic circuit and an electric circuit. In Fig. 7A we have the magnetomotive force sending the flux around the magnetic circuit against the opposition offered by the reluctance of the circuit. In Fig. 7B, we have a wire connected across a battery. Here the electromotive force of the battery is forcing current around the circuit against the opposition or resistance of the wire.

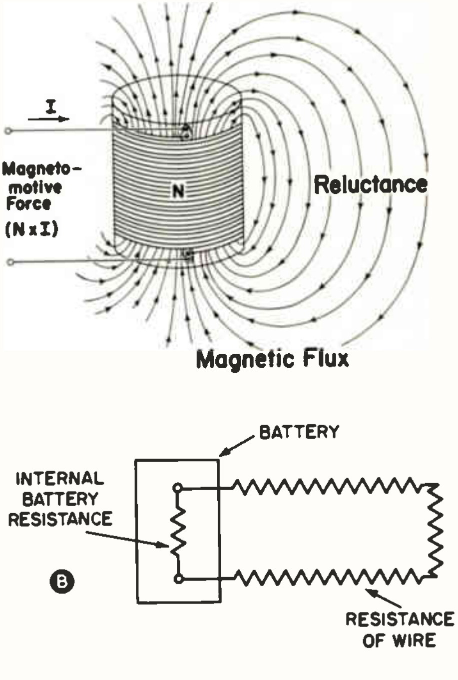


Fig. 7. Comparison between a magnetic circuit (A) and an electrical circuit (B).

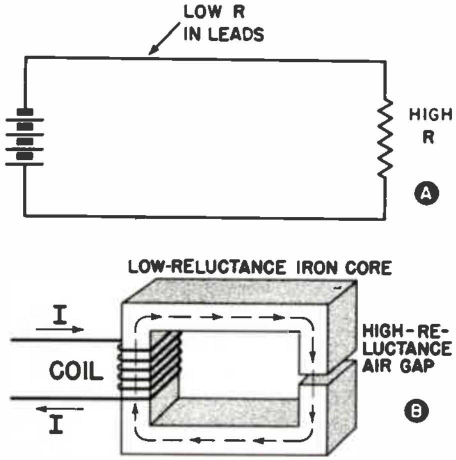


Fig. 8. In the electrical circuit at A, most of the opposition (resistance) to the current is in the resistor. The total resistance in the circuit is only slightly higher than the resistance of the resistor. In the magnetic circuit at B, most of the reluctance or opposition to the flux is in the air gap. The total reluctance in the circuit is only slightly higher than the reluctance of the air gap.

We have shown the whole length of the wire as a resistor. Here we see that the magnetomotive force is the equivalent of the electromotive force, the magnetic flux the equivalent of current, and the reluctance the equivalent of resistance.

We have a magnetic circuit that is similar to an electric circuit consisting of a resistor connected across a battery as shown in Fig. 8A. Here most of the resistance in the circuit is concentrated in the resistor; the resistance of the leads is small compared to that of the resistor. In the magnetic circuit of Fig. 8B, the iron core of the coil has an air gap. Most of the reluctance is concentrated in the air gap; the reluctance of the iron core is low in comparison to the reluctance of the air gap. One of the choke coils used in the power supply of a radio transmitter often has an air gap like this.

In an electric circuit, if we lower the resistance or opposition we can increase the current, and if we increase the resistance we reduce the current. Exactly the same situation exists in the magnetic circuit. If we lower the reluctance or opposition we increase the flux, and if we increase the reluctance we reduce the flux.

The reluctance in a magnetic circuit can be reduced by providing a better path through which the magnetic lines of force can flow. Materials such as iron and steel have a low reluctance, just as copper has a low resistance in an electric circuit. Therefore if a coil is wound on an iron core shaped like the one shown in Fig. 9, the magnetic lines will flow through the core as shown in the drawing. Because the iron has a low reluctance, there will be a much greater flux than there would

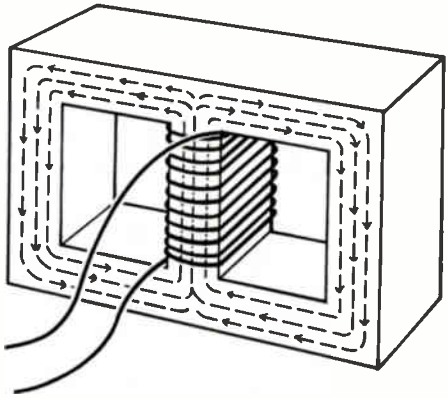


Fig. 9. There will be much greater flux if a coil is wound on an iron core like this than if the coil has an air core.

be if the same coil had an air core. Thus the flux in a magnetic circuit can be increased by providing a path of a magnetic material through which the magnetic lines of force can flow. Making a frame like the one shown in Fig. 9 of nonmagnetic material such as paper, glass, aluminum, or copper would not increase the flux, because these materials do not have a lower reluctance than air.

There are other factors that affect reluctance. Increasing the cross sectional area of the core will reduce the reluctance and increasing the length of the magnetic circuit will increase the reluctance.

PERMEABILITY

Silver, copper, and aluminum have different conductivities. Silver has the highest conductivity and is the best conductor, then copper and then aluminum. A copper wire has less resistance than an aluminum wire of the same size and length.

Similarly, different magnetic materials have different permeabilities. The permeability of the core material determines the total reluctance of the coil; when the permeability goes up, the reluctance goes down and vice versa.

The permeability of air and all other nonmagnetic materials is considered to have the numerical value of 1. Magnetic materials all have higher permeability values than 1, ranging from about 50 all the way up to 10,000 or even higher for certain special alloys. Thus if the permeability of a material is 10, we can expect 10 times the magnetic flux through this material than we would have through air for the same number of ampere turns.

MAGNETIC FLUX

You already know that magnetic flux in a magnetic circuit corresponds to current in an electric circuit. In an electric circuit, current is equal to the voltage in volts divided by the resistance in ohms. In a magnetic circuit the flux is equal to the magnetomotive force divided by the reluctance.

In practical magnetic circuits you will not have to calculate the magnetic flux. Even if you performed this calculation it would be of no value to you. However, it is important that you understand what magnetomotive force, reluctance, and magnetic flux are, and how they are related to each other.

You can increase the amount of flux in a magnetic circuit either by increasing the magnetomotive force or by decreasing the reluctance. You can decrease the amount of flux either by decreasing the magnetomotive force or by increasing the reluctance. Every change in flux is thus due to a change in either magnetomotive force or to a change in reluctance.

SUMMARY

Magnetic circuits are like electrical circuits in many ways. In a magnetic circuit there is a force which is the equivalent of voltage in an electrical circuit. We call this force a magnetomotive force. This force produces flux or magnetic lines of force which travel around the magnetic circuit. The flux or magnetic lines of force have some opposition; the opposition is known as reluctance. The magnetic lines of force are roughly the equivalent of the current in an electrical circuit and the reluctance is the equivalent of the resistance. In a circuit with a given magnetomotive force, if the reluctance is lowered, the flux in the circuit will increase. On the other hand, if the reluctance increases, the flux decreases.

Remember that the unit of magnetomotive force is an ampere-turn. A current of 1 ampere flowing through a coil of one turn produces a magnetomotive force of 1 ampere-turn. If we double the number of turns so that we have two turns and the current remains the same, the magnetomotive force produced will be two ampere-turns.

Remember the term permeability. The permeability of a material indicates the ability of the material to pass magnetic lines of force. The permeability of air is 1. Other non-magnetic materials such as paper, ceramic, glass etc. also have a permeability of 1 - in other words they act just like air insofar as a coil is concerned. However, magnetic materials such as iron and various alloys of magnetic materials have a much higher permeability than air. When we speak of a coil with a high permeability core we are talking about a coil with a core that has a much higher ability to pass magnetic lines of force than air.

Make sure that you remember these important terms used in conjunction with magnetic circuits. You will run into them many times in the future, and if you understand them now, then you'll understand the way in which they are used later. If you have any doubts about this section of this lesson be sure to review before going on. Once you are sure you have mastered the material in the lesson, do the self-test questions. Again, if you have trouble with any of the self-test questions, don't hesitate to go back to the text and restudy it. The purpose of the self-test questions is to help you be sure you have mastered the important points in the section of the lesson. If there is any self-test question you are not sure of, this indicates that you need to go back and spend some extra time on this section of the lesson before going ahead.

SELF-TEST QUESTIONS

(a) Fill in the missing word: Magnetic lines of force form ____ loops.

(b) Where will most of the lines of force produced by a coil be concentrated?

(c) What type of coil is a coil wound on a cardboard form?

(d) What are laminations?

(e) What purpose does an iron-core serve in a coil?

(f) What is magnetomotive force?

(g) What is the unit of magnetomotive force?

(h) If the current flowing through a 25-turn coil is 2 amperes, how many ampere-turns are produced?

(i) What is reluctance?

(j) Does the magnetic circuit in an air-core coil have a higher reluctance than a magnetic circuit in an iron-core coil?

(k) Which has the lowest reluctance, paper, air, aluminum or copper?

(l) What is permeability?

(m) What is the relation between flux, magnetomotive force and reluctance?

Using Coils To Produce Voltage

In most of the electronics applications of coils with which you are concerned, coils will be used to produce a voltage. An obvious example of this application is the transformer. In a transformer, a voltage is applied to one winding and this voltage causes a current to flow through this winding. This sets up a magnetic field, which in turn induces a new and completely separate voltage in another coil. Here two coils have been used to produce a voltage.

Another type of device where a coil is used to produce voltage makes use of a coil placed in the field of a permanent magnet to take a wave or signal other than an electrical signal and produce an electrical signal from it. Such a device is called a transducer. An example of a transducer using this principle is a dynamic microphone. A dynamic microphone uses coils placed in a magnetic field to convert an audio signal, which is actually a wave or vibration in air, to an electrical signal, which is the electrical equivalent of sound.

If you understand how a voltage can be produced by a coil, you will have mastered the most important point in understanding how coils work. To see how a voltage can be induced in a coil, we must first learn something about flux and flux linkages and then see how changing the flux linkages of a coil will produce a voltage in a coil.

FLUX LINKAGES

Let us see what we mean by flux linkage. Suppose we have a magnet that produces a single magnetic line of force. If the magnet is brought near a coil having one turn such as shown in Fig. 10A, we will have one magnetic line linking with or passing through a one-turn coil, and we will have one flux linkage. If we had ten turns on the coil and the one magnetic line of force passed through all ten turns, then we would have ten flux linkages as shown in Fig. 10B. However, if the single magnetic line passed through and linked only six turns of the 10-turn coil, as shown in Fig. 10C, we would have only six flux linkages. Thus the term

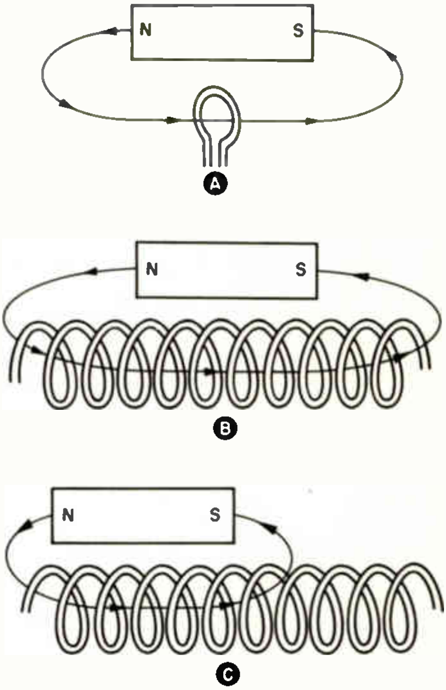


Fig. 10. How the number of flux linkages can be changed. In A there is one flux linkage; in B, ten; and in C, six.

"flux linkage" is an indication of the number of magnetic lines of force passing through and linking the turns on the coil. If we have a magnet that produces 100 magnetic lines, and the entire 100 lines linked to a coil having 80 turns, the number of flux linkages would be 80 times 100, or 8000 flux linkages.

Changing Flux Linkages.

Now let's look at Fig. 11A. Here we have a magnet with 10 magnetic lines of force, but actually only two of them are cutting through a coil with 5 turns on it, so we have a total of 10 flux linkages. As you can see, part of the flux is lost--it does not cut through the coil. This is called leakage flux or flux leakage. If we suddenly move the magnet to the position shown in Fig. 11B so that the magnet is placed inside the coil and all ten lines cut through the five turns of the coil, we have a total of 50 flux linkages. When the number of flux linkages increases from 10 to 50 there will be a voltage induced in the coil. This voltage is known as an induced voltage.

If the magnet is then moved away from the coil so that the number of flux linkages is changed from 50 back to 10, we will again have a voltage induced in the coil.

In each of the two examples given, we had a change of 40 flux linkages. If we had a stronger magnet so that the number of lines of force was greater, and therefore the change in flux linkages was greater, we would have a greater voltage induced in the coil.

In moving the magnet either towards or away from the coil, the voltage that will be induced in the coil will depend upon the speed with which the magnet is moved. If the magnet is moved slowly so that the number of flux linkages changes slowly, the voltage induced in the coil will be small. However, if the magnet is moved rapidly so that the change in flux linkage occurs very quickly, the voltage induced in the coil will be higher. If it took one second to move the magnet so that the number of flux linkages changed from 10 to 50, we would get a certain voltage induced in the coil. The exact value is not important to this discussion. However, if we were to move the magnet so that the number of flux linkages was changed from 10 to 50 in 1/100th of a second, we would get exactly 100 times as much voltage as before. The faster the rate of change in flux linkages, the greater the induced voltage will be.

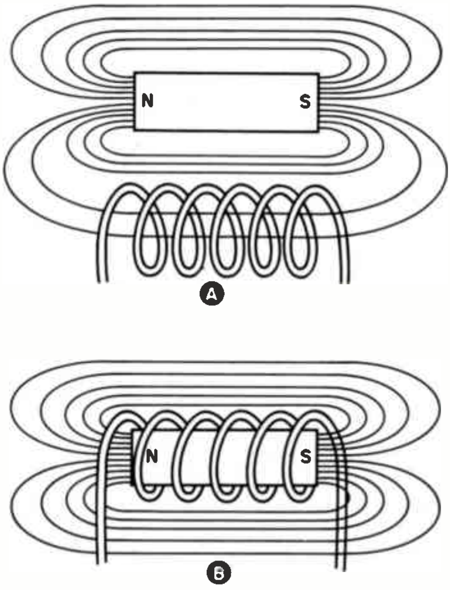


Fig. 11. In A we have 10 flux linkages; in B we have 50 when the same magnet is moved inside the coil.

LENZ'S LAW FOR COILS

The voltage induced in a coil always acts in a definite direction. In other words, the voltage has a definite polarity. This polarity at any given instant depends on just two things--on the direction of the original flux, and on whether the flux linkages are increasing or decreasing.

The exact relationship between these things is expressed by a famous electrical law known as Lenz's Law. The law is named after the man who was the first to realize that the direction in which an induced voltage will act can always be predicted before it is produced.

When the number of flux linkages cutting a coil is changed, a voltage will be induced in the coil. This induced voltage will have a polarity such that if the circuit is complete, it will send a current through the coil which opposes the change in magnetic flux. In other words, if the flux linkages are increasing, the induced voltage will tend to send a current through the coil that would produce a magnetic flux which would oppose the original coil flux to try to keep it from increasing. On the other hand, if the flux linkages are decreasing, the induced voltage will be of such a polarity that it will produce a current which in turn will produce a flux which aids the original flux and tends to prevent the flux from decreasing.

This is an extremely important law and can be better understood by referring to the circuits shown in Fig. 12. In Fig. 12A, we have a magnetic circuit with two flux lines cutting through a 5-turn coil, which gives us ten flux linkages. As the magnet is moved away from the coil, reducing the number of flux linkages as shown in Fig. 12B, a voltage will be induced in the coil, and current will flow through the coil. Current flowing through the coil will set up a magnetic field which will aid the flux linkages already existing. As long as the number of flux lines is changing, the induced voltage will be present and will cause the induced current to produce flux lines as shown.

If, as shown in Fig. 12C, the magnet is moved back into the coil, the number of flux linkages would tend to increase. However, a voltage will be induced in the coil that will cause

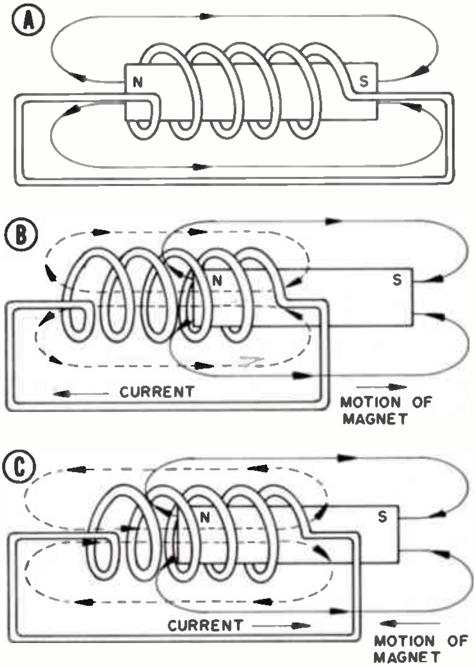


Fig. 12. Changing the number of flux linkages induces a voltage in the coil. The polarity of the voltage depends upon whether the number of flux linkages is increasing or decreasing.

a current to flow in the opposite direction and set up its own lines of force to oppose the flux lines from the magnet. In other words, if there is any change in the number of flux linkages through the coil, a voltage is induced in that coil that will cause a current to flow which in turn produces its own flux to oppose the change in flux linkages.

If the number of flux linkages is decreasing, the induced voltage will have a polarity such that it will cause a current to flow to oppose this decrease in flux linkages; and on the other hand, if the flux linkages are increasing, then the induced voltage will have a polarity that will cause a current to flow to oppose this increase in flux linkages.

METHODS OF CHANGING FLUX LINKAGES

There are three methods of producing changes in the flux linkages in a coil. They are: by cutting through magnetic lines of force; by changing the reluctance; and by changing the current flowing in the coil.

Cutting Lines of Force.

You have already seen an example of this method of producing changes in flux linkages when you studied generators in an earlier lesson. You learned that when a conductor is moved through a magnetic field it cuts the magnetic lines of force, and a voltage is induced in the conductor. We get this induced voltage because the motion of the conductor changes the flux linkages as the conductor passes through the magnetic lines of force.

In a generator, instead of moving a single wire through a magnetic field, a coil is rotated in the magnetic field. As the coil is rotated, it moves through and cuts through the magnetic lines of force produced by a permanent magnet or an electromagnet, and a voltage is induced in the coil. The voltage induced in the coil will have a polarity such that the current that will flow when the coil is connected to an external circuit will set up a magnetic field in the coil which opposes the change in flux linkages producing the voltage.

Changing the Reluctance.

Any change in the reluctance of a magnetic circuit will change the amount of flux which passes through the coil, thus changing the flux linkages through the coil and inducing a voltage. Remember, whenever there is a change in flux linkages, a voltage is induced.

An example of this method of producing a voltage is the variable reluctance phono pickup used in many record players. A simplified drawing of one is shown in Fig. 13. The needle, or stylus, is mounted on a cantilever spring, which moves between two coils. The other end of the cantilever spring is connected to the south pole of a permanent magnet. A T-shaped yoke connects the other end of the magnet to two pole

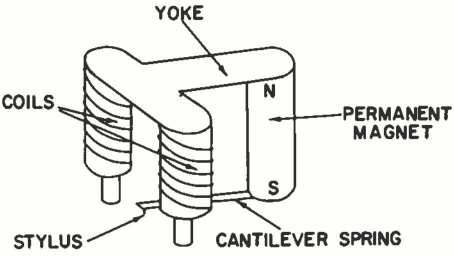


Fig. 13. A variable reluctance phono pickup.

pieces on which two coils are wound. The flux path goes from the magnet through the yoke, and the two pole pieces, across the air gap to the cantilever spring, and through it back to the magnet. As the needle follows the record grooves, it moves from side to side, nearer one or the other of the two coils. As it does so, the air gap on one side decreases, so the reluctance on that side decreases, and the flux increases. At the same time, the air gap on the other side becomes wider, increasing the reluctance and decreasing the flux. Since the flux changes are in opposite directions, the voltages induced in the two coils will be of the opposite polarity. The two coils are connected in such a way that the two voltages are added in the output. The change in flux linkages will induce a voltage in the coil.

Changing the Coil Current.

When two coils are arranged as shown in Fig. 14, the flux produced by coil L1 passes through coil L2. As long as the current through L1 remains constant, the flux produced by this coil will remain constant, and there will be no change in the flux linkages in L2. However, if the current is changed by changing the setting of the rheostat, there will be a change in the flux produced by L1 and hence a change in the number of flux linkages in L2. This will induce a voltage in L2.

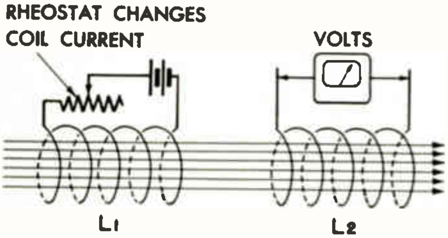


Fig. 14. When two coils are arranged as shown above, the flux produced by one passes through the other.

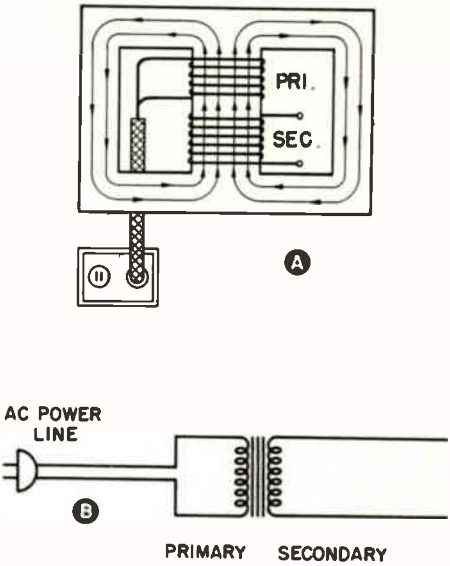


Fig. 15. A power transformer. The primary winding is connected directly to the power line. As the current through the primary working varies, the flux produced by L1 will vary, resulting in a change in flux linkages through the secondary winding, inducing a voltage in the secondary.

Of course, this is not a practical way of inducing a voltage in L2 because the rheostat setting would have to be changed continually and at a rapid rate in order to produce any appreciable voltage in L2. A more practical application would be to apply an ac voltage to L1 in place of the battery and the rheostat.

Since the ac voltage is continually changing, this means that the flux is constantly changing, which in turn will result in there being a voltage continually induced in L2.

A practical application of this principle is in the power transformer as shown in Fig. 15. We have already mentioned the transformer several times before and you are aware that a transformer is simply two coils wound on a common core. In the transformer shown in Fig. 15, the one winding called the primary is connected directly to the ac power line. The ac voltage which is a varying voltage will cause a varying current to flow through the primary winding. As the current varies, the flux produced by the primary will change, resulting in a change in the flux linkages cutting the secondary winding. This change in flux linkages will induce a voltage in the secondary winding. As we pointed out before, whether this voltage is higher or lower than the primary voltage will depend upon whether the secondary winding of the transformer has more or fewer turns than the primary winding.

SUMMARY

There are several important facts that you should remember from this section of the lesson. First, remember that a voltage is induced in a coil when the number of flux linkages changes. Either an increase in the number of flux linkages or a decrease in the number of flux linkages will induce a voltage in the coil.

Lenz's Law of coils is important. It states that the induced voltage always acts in such a direction that it tends to oppose the original change in flux linkages.

Changes in flux linkages can be produced by cutting through magnetic lines of force, by changing the reluctance in the magnetic circuit or by changing the current flowing through the circuit.

In the next section of this lesson you will learn more about coils. You will learn how the electrical characteristics of coils are expressed and also see why the opposition that a coil offers to the flow of ac through it is much higher than it is to dc. However, before going ahead with the next section of the lesson, it is important that you understand the material covered in this section. Therefore you should review this section if necessary and then answer the self-test questions. Be sure you are able to answer all of the following self-test questions before you go ahead with the next section of the lesson.

SELF-TEST QUESTIONS

(n) What is meant by flux linkages?

(o) If three magnetic lines of flux cut through four turns of a coil, how many flux linkages have we?

(p) If one hundred flux linkages cut through a coil, and this number of flux linkages does not change, what will the voltage induced in the coil be?

(q) According to Lenz's Law, if a change in the number of flux linkages cutting a coil occurs, will the voltage induced in the coil produce a current, which in turn will build up a magnetic flux that will aid or oppose the original change in flux linkages?

(r) When the number of flux linkages cutting a coil is reduced, will the field produced by the induced voltage aid or oppose the original lines of force?

(s) Name three methods of changing flux linkages.

(t) Give a practical example where changing the reluctance in a magnetic circuit is used to produce a voltage.

(u) Give a practical example of where changing the coil current produces a voltage.

Inductance

In the preceding section of this lesson you learned that if the number of flux linkages cutting the turns of a coil changes, there will be a voltage induced in the coil. The exact amount of voltage that will be induced in the coil will depend upon how great the change in flux linkages is, and how rapidly it occurs. It will also depend upon the coil itself. The property of the coil that will govern or determine the voltage induced in the coil is called inductance. The inductance of a coil will depend upon the number of turns of wire on the coil and upon the permeability of the core material. Saying that a coil has inductance is just about the same as saying a resistor has resistance. Inductance is a basic property of a coil and it indicates how much voltage will be induced in the coil for a given change in flux linkages. Before we go further with this idea of inductance, you should learn something about self-induced voltages.

SELF-INDUCED VOLTAGES

When a coil is brought near a magnetic field and the strength of the field is suddenly changed, there will be a change in the number of flux linkages through the coil. You know that this will result in a voltage being induced in the coil.

However, now let us consider a coil that is completely removed from any external magnetic field. If a voltage source is connected to the coil, current will flow through the coil and this current will set up a magnetic field. The magnetic field produced by the coil will produce lines of flux. These lines of flux will link through the turns of the coil as shown in Fig. 16.

If the current flowing through the coil is suddenly changed, the strength of the magnetic field will change and this will result in there being a change in the number of flux linkages passing through the turns of the coil. This will have exactly the same effect as changing the flux

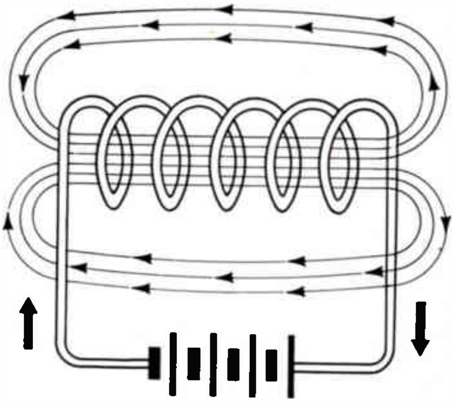


Fig. 16. If a voltage source is connected to a coil, current will flow through the coil and a magnetic field will be set up.

linkages produced by an external magnet will have. There will be a voltage induced in the coil and this voltage will be such that it will tend to oppose the change produced. In other words, the induced voltage will cause a current to flow in such a direction as to produce a magnetic field which tends to oppose the change in the magnetic field. The voltage induced in this manner is known as self-induced voltage.

It is important for you to realize that an induced voltage in a coil always opposes the change producing it. For example, in the circuit shown in Fig. 16, if the voltage is reduced to lower the current and hence the number of flux linkages, the self-induced voltage induced in the coil will have a polarity that both aids the applied voltage and tries to keep the current constant so that the number of flux linkages will not change. On the other hand, if the applied voltage is suddenly increased, then the voltage induced in the coil will oppose the applied voltage to, once again, try to keep the current flowing through the coil constant and hence the number of flux lines constant.

The induced voltage in a coil obeys Lenz's Law. Its polarity is such that it tries to oppose the change that produced it.

UNITS OF INDUCTANCE

For a given change in flux linkages, the voltage that will be induced in a coil will depend upon the inductance of the coil. The unit of inductance is the henry. It is named after Joseph Henry, an outstanding scientist who did a great deal of experimenting with coils.

There are a number of scientific ways of defining the henry, but these are of no importance to the electronics technician. One simple definition of the henry that can be used is as follows: if the voltage induced in a coil is 1 volt when the strength of the current flowing through the coil changes at a rate of 1 ampere per second, the coil has an inductance of 1 henry. In other words, if a coil has an inductance of 1 henry, a current change of 1 ampere per second will induce a voltage of 1 volt in the coil.

Large iron-core coils frequently have quite high inductances. You will find iron-core coils in electronic equipment having inductances of 20 or 30 henrys. In some cases you may find iron-core coils having inductances ranging as high as 1000 henrys.

Most air-core coils have a very small inductance. For convenience in specifying inductance values of air-core coils and some small iron-core coils, two other units are used, the millihenry and the microhenry. Just as the milliampere is one thousandth of an ampere, the millihenry is one thousandth of a henry; just as a microampere is one millionth of an ampere, the microhenry is one millionth of a henry. The unit millihenry is usually abbreviated mh and the microhenry is abbreviated μh.

To convert from henrys to millihenrys or microhenrys you use exactly the same procedure as in converting amperes to milliamperes or microamperes. To convert henrys to millihenrys, you multiply by 1000 or simply move the decimal point three places to the right. To convert henrys to microhenrys you multiply by 1,000,000 or move the decimal point six places to the right. To convert millihenrys to microhenrys, you multiply by 1000 or move the decimal point three places to the right.

To convert from microhenrys to henrys, you divide by 1,000,000, or move the decimal point six places to the left. To convert from millihenrys to henrys, you divide by 1000 or move the decimal point three places to the left. To convert from microhenrys to millihenrys you divide by 1000 which is the same as moving the decimal point three places to the left. If you have no difficulty converting from amperes to milliamperes and microamperes and back again to amperes you should have no problem converting between henrys, millihenrys and microhenrys.

FACTORS AFFECTING INDUCTANCE

There are several factors that affect the inductance of a coil. As you might expect, one of the chief factors is the number of turns on the coil. You can expect a coil having 200 turns to have a higher inductance than a coil having 100 turns would on the same type of core.

The inductance of a coil is also affected by the shape and size of the coil. As an example, an air-core coil wound on a round form six inches in diameter will have a higher inductance than a coil with the same number of turns wound on a form one inch in diameter. In the coil with the smaller diameter, many of the lines of flux will escape or cut through only a few turns of the coil; in other words there will be considerable flux leakage. On the other hand, in the larger coil more flux lines will cut through each turn of the coil, resulting in a greater number of flux linkages, which in turn will give the coil a greater inductance.

The inductance of a coil is affected by the core material. If a magnetic material is placed in the core of a coil, the magnetic path will have a much lower reluctance; there will be more flux and a much greater number of flux linkages than there would be in a similar coil without an iron-core. The exact material placed inside the coil also affects the inductance. The higher the permeability of the core material, the greater the inductance of the coil will be.

Before leaving this section of the lesson it should be pointed out that inductance is not limited to coils alone. Even a straight wire has some inductance, because when a current flows through the wire, a magnetic field is set up around the wire and the wire will be cut by magnetic lines. Of course, the inductance of a straight wire is much lower than it would be if the wire were wound into a coil, but nevertheless every piece of wire does have inductance. In most cases this inductance is so low it has no effect on the circuit performance, but in some ultra-high-frequency electronic equipment straight wires or tubing are actually used as "coils."

Because the most important property of a coil is its inductance, electronics men often call coils "inductors" or "inductances." The term inductance not only includes coils, but in the case of ultra-high-frequency equipment may include a straight piece of tubing that is to be used as the inductance in one of the circuits.

INDUCTIVE REACTANCE

You have learned that when a coil is connected to a voltage source as in Fig. 16, and the voltage is changed, there is a voltage induced in the coil that opposes the change in voltage. Now let us consider what happens when a coil is connected to an ac voltage source as in Fig. 17. Here the voltage is continually changing.

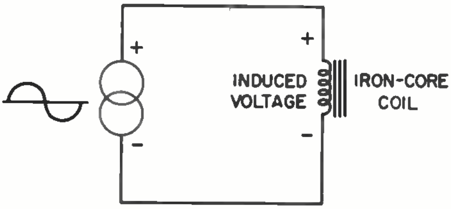


Fig. 17. A coil connected to an ac voltage source.

During the first quarter cycle when the ac voltage is increasing and has the polarity shown in Fig. 17, the polarity of the induced voltage will be as shown so it will oppose the ac voltage as it tries to increase. Thus, the induced voltage acts to oppose and limit the change in current in the coil. If there were no voltage induced in the coil, the current would increase as the voltage increased, and the actual value of current flowing at any instant would depend only on the voltage applied and the dc resistance of the coil. However, since the induced voltage is of the opposite polarity to the applied voltage, the induced voltage has the effect of opposing the applied voltage and limiting the current change in the coil. This self-induced voltage is known as "counter" or "back" emf (electromotive force). It is the induced ac voltage that appears across the coil. This ac voltage drop is just the same as the voltage drop across a resistor caused by current flowing through a resistor. In other words, the counter emf is the ac voltage drop across a coil caused by the opposition that the coil offers to the alternating current. This opposition that the coil offers is not the same as resistance because it affects only ac, and not dc. The opposition is known as inductive reactance and it is measured in ohms.

The amount of voltage induced in a coil will depend upon how rapidly the change in flux linkages occurs. When an ac voltage is applied to a coil, the speed with which the number of flux linkages changes depends upon the frequency of the ac voltage. Thus the change in flux linkages occurs more rapidly if the frequency is 100 cycles than it would if the frequency were only 10 cycles. Therefore an ac current with a frequency of 100 cycles flowing through a coil will induce more voltage than a current of the same strength but a frequency of only 10 cycles. This means that the inductive reactance depends upon the frequency.

The inductive reactance of a coil can be determined by multiplying the inductance of the coil in henrys times 6.28 times the frequency in cycles.

Electronics technicians use symbols to provide a short convenient way of expressing this relationship. The symbol used for reactance is X. A small capital letter L following the X and written X_L is used to indicate inductive reactance. The letter f is used to represent frequency, and the letter L is used to represent inductance. Thus the expression for inductive reactance of a coil in ohms can be written:

$$X_L = 6.28 \times f \times L$$

The number 6.28 is two pi. Pi is the Greek letter π (pronounced pie) which represents the number 3.14. You have probably seen this number before--it is used to find the area of a circle. Remember that the area of a circle is π times the radius squared. 2π is 6.28, which is a number that appears in many electrical formulas. Sometimes you will see the expression for inductive reactance written:

$$X_L = 2\pi fL$$

Now let's see how we use this formula to find the inductive reactance of a coil.

Example 1: Suppose we want to know the inductive reactance of a 50-henry choke at 100 cycles. The formula is:

$$X_L = 6.28 \times f \times L$$

Substituting 100 for f and 50 for L gives:

$$X_L = 6.28 \times 100 \times 50$$

Multiplying these numbers gives us 31,400 ohms. This is the inductive reactance of the coil at a frequency of 100 cycles. At a frequency of 50 cycles, the inductive reactance would be half this figure, and at a frequency of 200 cycles per second, the inductive reactance would be twice this figure. We say that the inductive reactance of a coil varies directly as the frequency varies. If the frequency increases, the reactance increases, and if the frequency decreases, the reactance also decreases.

Example 2: Suppose we want to know the inductive reactance of a 10-henry choke at a frequency of 100 cycles. Substituting 100 for f and 10 for L gives us:

$$X_L = 6.28 \times 100 \times 10$$

Multiplying this gives us:

$$X_L = 6280 \text{ ohms.}$$

Notice that this is less than in the case of the 50-henry coil. Thus the inductive reactance also varies directly as the inductance of the coil varies. Reducing the inductance reduces the reactance and increasing the inductance increases the reactance.

As an electronics technician you will seldom have to work on a problem of this type. However, it is important for you to remember that the inductive reactance of a coil varies directly both with the frequency and with the inductance of a coil.

You might wonder what the inductive reactance is of a small coil consisting of only a few turns. At low frequencies of a few hundred cycles, the reactance is so low that in most cases it can be ignored. However, when small coils are used in high-frequency circuits, their inductive reactance can be appreciable. Let's take as an example a 10-microhenry coil used at a frequency of 100 megacycles.

10 microhenrys is .000010 henry, and 100 megacycles (abbreviated mc) is 100,000,000 cycles.

$$X_L = 6.28 \times f \times L$$
$$X_L = 6.28 \times 100{,}000{,}000 \times .000010 = 6280 \text{ ohms.}$$

Thus, even though the inductance of the coil is quite small, at the frequency of 100 mc it has as high an inductive reactance as the 10-henry coil had at 100 cycles.

We mentioned previously that inductive reactance is the opposition a coil offers to the flow of ac current through it. A coil has no inductive reactance to dc. You can see that this must be true from the formula for inductive reactance. The frequency of dc is zero and so if we substitute zero in the formula for inductive reactance, then we have 6.28 × 0 × L. Whenever you multiply anything by 0, no matter how large it is, the result is 0, so the inductive reactance is 0. The only opposition a coil will offer to the flow of dc through it is due to the resistance of the wire used to wind the coil. The wire will have a certain resistance, and this resistance will oppose the flow of dc through the coil in just the same way as it would if it were one long piece of wire and we tried to pass dc through it. The ac reactance of a coil, on the other hand, is an entirely different thing; it is the opposition the coil offers to the flow of ac through it due to the inductance of the coil, and it will be much higher than the dc resistance of the coil.

MUTUAL INDUCTANCE

When two coils are placed near each other so that some of the flux produced by one coil will cut through the turns of the other coil, the coils are said to be mutually-coupled through their magnetic fields. The coils might actually be wound on the same iron core or they might simply be placed near each other. When coils are placed so they are mutually coupled, any change in the flux in one coil will induce a voltage in the other coil.

Mutual inductance is measured in henrys, just as the inductance of a single coil. The mutual inductance is usually represented in formulas by the letter M. The greater the value of mutual inductance, the greater will be the voltage in one coil when the current through the other changes.

Mutual inductance is defined in the same way as inductance - when a primary current changes at a rate of 1 ampere per second, if the voltage induced in the secondary coil is 1 volt, the mutual inductance is 1 henry.

Mutual inductance depends upon the size of both coils, the number of turns of each coil and how many flux linkages from one coil cut the turns of the other coil.

COILS IN SERIES AND PARALLEL

When we consider coils connected in series or in parallel, there are two different cases to consider. The first and simplest is if the coils are located some distance from each other so that their magnetic fields do not affect each other. When the coils are connected in series as shown in Fig. 18A, the combined inductance is the sum of the individual inductances. In other words, the total inductance is obtained simply by adding the inductances of the individual coils. This should be easy to remember because in this respect coils are like resistors.

When coils are connected in parallel as shown in Fig. 18B, the total inductance will be less than the inductance of the smallest coil in the

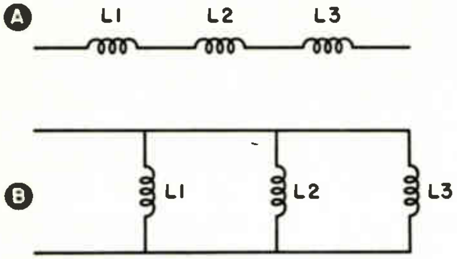


Fig. 18. Coils connected in series (A): coils connected in parallel (B).

group. Again, this is just like resistors connected in parallel - remember that when resistors are connected in parallel, the total resistance is always less than the resistance of the smallest resistor.

It is easy to see why coils connected in parallel act this way. For example, looking at Fig. 18B, if L1 has an inductive reactance of 100 ohms and is connected across a 100-volt source, an ac current of 1 amp would flow through the coil. If the second coil of equal inductance is connected in parallel with it, an ac current of 1 amp will also flow through it. Now we have a current of 2 amps flowing in the circuit and therefore, the opposition or inductive reactance must have decreased. This means that the total inductance of the two coils in parallel must have decreased. In fact, with two equal coils, the effective inductance of the two in parallel will be equal to one half the inductance of either coil.

When coils connected in series are placed close together so that some mutual inductance exists, there is interaction between the coils, and the combined inductance can no longer be figured simply by adding the inductances of the individual coils. In this situation, we must consider the mutual inductance in the circuit and also how the coils are connected together.

Let us look at the first case, where the two coils are connected in series so that the flux from one coil aids the flux from the other. In other words, the magnetic lines are flowing in the same direction. Here if the inductance of the two coils is represented by L1 and L2 and the mutual inductance by M, the total inductance (L_T) of the two coils connected in series will be equal to:

$$L_T = L1 + L2 + 2M$$

If the connections to one of the coils are reversed, its magnetic field will oppose the magnetic field of the other. Under these circumstances the total inductance of the two coils connected in series will be:

$$L_T = L1 + L2 - 2M$$

SUMMARY

You have studied a great deal of important material about coils in this section and it would be worthwhile to read the section over several times to be sure that you have understood everything covered.

You have learned that the electrical property that describes coils is called inductance, and that inductance is measured in henrys. A coil has an inductance of 1 henry when a current change of 1 amp per second induces a voltage of 1 volt in the coil.

You learned that when the current flowing through a coil changes, there is voltage induced in the coil that opposes the change that produces it. This voltage is a self-induced voltage and is called counter emf or back emf.

Coils have a property called inductive reactance. Inductive reactance is the opposition that a coil offers to the flow of ac through it. Inductive reactance is measured in ohms and is somewhat similar to resistance inasmuch as it opposes the flow of ac through the coil.

When two coils are placed near each other, the flux lines of one coil will cut through the other coil, and the coils are said to be mutually-coupled. The amount of coupling is determined by the nearness of the coils to each other and by the shape and size of the coils. This coupling is called mutual inductance. The mutual inductance of two coils is measured in henrys.

When coils are connected in series, the total inductance is equal to the sum of the individual inductances, and when they are in parallel, the total inductance is less than the inductance of the smallest coil. When mutually-coupled coils are connected in series, the total inductance is $L1 + L2 + 2M$ when the magnetic field of the two coils aid each other, and $L1 + L2 - 2M$ when the magnetic fields oppose each other.

SELF-TEST QUESTIONS

(v) What is the name given to the property of a coil which will determine the voltage induced in it?

(w) What is a self-induced voltage?

(x) If the voltage applied to a coil is suddenly increased, will the self-induced voltage produced in the coil aid or oppose the applied voltage?

(y) What is the unit of inductance?

(z) How is the unit of inductance defined?

(aa) Name three factors which affect the inductance of a coil.

(ab) What is the inductive reactance of a coil?

(ac) What is the unit in which the inductive reactance of a coil is measured?

(ad) What is the inductive reactance of a 10-henry coil at a frequency of 60 cycles?

(ae) What is meant by mutual inductance?

(af) If two coils, one having an inductance of 6 henrys and the other having an inductance of 8 henrys are placed some distance apart so that there is no mutual inductance between them, what will the total inductance of the two coils be if they are connected in series?

(ag) Two coils, one having an inductance of 4 henrys and the other having an inductance of 3 henrys have a mutual inductance of 2 henrys. If the coils are connected in series aiding, what will the total inductance be?

(ah) If an 8-henry coil and a 7-henry coil that have a mutual inductance of 3 henrys are connected in series opposing, what will the total inductance of the two coils be?

(ai) Convert 2.2 henrys to millihenrys.

(aj) Convert 100 microhenrys to henrys.

Ohm's Law for Coils

You will remember from earlier lessons that the current that will flow in a circuit depends upon the voltage applied and upon the resistance of the circuit. This rule can be applied to ac circuits as well as dc circuits, but in an ac circuit, you substitute the total opposition offered to the flow of current for the resistance. In an ac circuit, the total opposition to current flow is called impedance and is represented by the letter Z. In this section of this lesson, you will study Ohm's Law for coils, you will learn what impedance is and how to find impedance in ac circuits, and you will learn about another important thing in ac circuits which is called phase.

PHASE

Before you can understand why impedance is important in ac circuits you must understand what we mean by phase. Phase is important. It is something that you will run into all the way through your study in electronic circuits. Time and time again you will see the expressions, "in phase", "out of phase" and "phase shift." Since phase is so important, learning what it is now will simplify your studies later.

In a circuit made up only of resistance, if we increase the voltage, the current will increase immediately. Changes in current can be produced instantly by changing the voltage in the circuit. In other words, the current follows the voltage changes instantly. If the voltage increases, the current increases instantly; if the voltage decreases, the current decreases instantly. The current is in phase with the voltage. This idea simply means the change in the voltage will produce the same change in the current flowing in the circuit.

This is not true of circuits containing coils. If you have a constant dc voltage connected across a coil, the current that flows depends only on the dc resistance of the coil; in other words, the resistance of the wire used to wind the coil. If you suddenly increase the voltage applied to the coil, there is immediately a change in the number of flux linkages cutting the various turns of the coil. This induces a voltage in the coil, and the induced voltage opposes the change in applied voltage. When the current changes because of the increase in applied voltage, it will be limited by the induced voltage as well as the resistance. The inductance of the coil opposes the change in current through the coil - this effect is called inductive reactance. Gradually the current will increase from the value that it was originally if the voltage were increased. As the current increases, it finally reaches its new value; the self-induced voltage in the coil decreases until finally when the current becomes constant, the self-induced voltage in the coil will disappear.

Now let us look at the circuit shown in Fig. 19. Here we have a resistor and a coil connected in series and the two are connected across an ac generator. We are

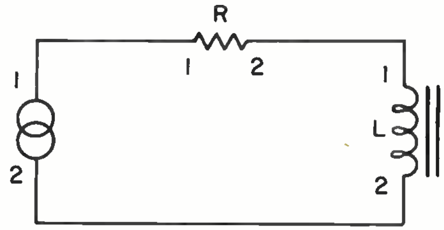


Fig. 19. A coil and resistor connected in series across an ac source.

going to examine the ac current flowing through the circuit to see what happens to the voltage across the resistor and the voltage across the coil, as the current goes through its cycle.

In Fig. 20A we have shown a single current cycle from the generator in Fig. 19. At the present, we are not worried about the voltage across the generator, we are simply concerned with the current. Remember that the ac voltages and current waveforms from the generator will be sine waves. The start of the sine wave cycle is marked point A. Let's consider that at this instant current is just starting to flow from terminal 1 of the generator around the circuit towards terminal 1 of the resistor. At the instant the cycle starts at terminal A, the current is increasing at its maximum rate of change. Notice that as the cycle moves from point A to point B, the curve is flattening out until finally at point C the current is neither decreasing or increasing, it is at a constant value for just an instant. From point C to point D the current begins to decrease. The rate at which it decreases is increasing from C to D and it continues to change at an even more rapid rate until it reaches point E at which instant the current is at 0 for just a moment. However, even though the current is at 0 for an instant at point E, the rate of change is very rapid; the instant before it reaches point E it is flowing in one direction, exactly at point E it drops to 0 and then at the instant it passes point E and starts towards point F, it begins to flow in the opposite direction. As the cycle moves from E to F, the rate at which the current is changing begins to decrease until finally at point G, once again while the current is flowing at its maximum value, the rate at which it is changing for just an instant at point G drops to 0. From point G to point H, the current again starts to drop to 0 and the rate at which it is dropping to 0 begins to

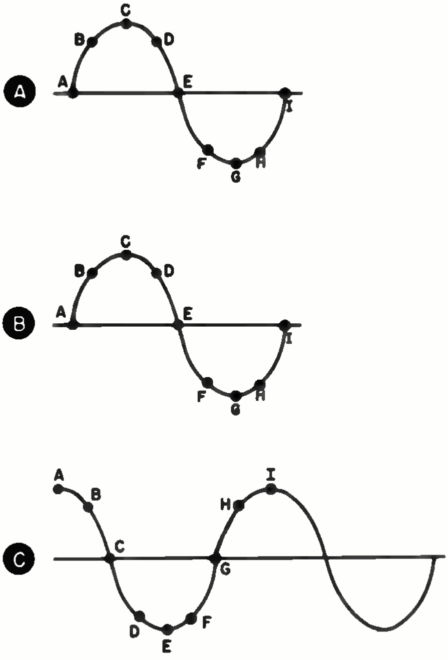


Fig. 20. Generator current is shown at A, resistor voltage at B and coil voltage at C.

increase from point G to point H and continues to increase until it reaches its maximum rate of change at point I.

Now let us see what happens as this current cycle flows around the circuit. Let us consider the voltage across the resistor R first. As the current flows from terminal 1 to terminal 2 of resistor R, the voltage that will be produced across the resistor will depend upon the current flowing through the resistor. As the current wave builds up from point A to point B and then to point C as shown in Fig. 20A, a voltage wave will be built up as shown in Fig. 20B. Point A represents 0 voltage and point C represents maximum voltage. Maximum voltage at point C on the curve B will be reached at exactly the same instant as the maximum current flow is reached at point C on curve A. As the current through the resistor begins to decrease and finally reaches 0 at point E on curve A, the voltage across the resistor will follow curve B reaching 0 at the same instant or at point E on curve B. As the current goes through the other half cycle and flows in the opposite direction, a voltage with the opposite polarity will be produced across the resistor. When the current reaches its maximum value at point G on curve A, the voltage will reach its maximum value with the opposite polarity at point G on curve B. As the last quarter of the cycle is completed and the current curve A drops from G to I, the voltage curve B will also drop from G to I.

Notice that throughout the entire cycle the voltage across the resistor was exactly in step with the current flowing through it. We say that the current and voltage are in phase.

Now let us consider what happens across the coil. We already mentioned that in curve A at point A, the current is changing at its maximum rate. Current is leaving terminal 1 of the generator and flowing around the circuit back to terminal 2. This means the current will try to flow through the coil from terminal 1 to terminal 2. The instant the current tries to build up through the coil a voltage will be induced in that coil which will oppose the change in current through it. The amplitude of the voltage will depend on the rate at which the current is trying to change. Since at point A on curve A, the change in current is at its maximum value, the maximum voltage will be built up across L. The polarity of the voltage will be such that it will oppose the current flowing in the circuit. This means that we could get the same effect by putting a battery in the circuit that would prevent the current from flowing through the coil. In order to do this we would have to connect the battery so that terminal 1 was negative and terminal 2 positive; this would oppose the current trying to flow around the circuit.

In Fig. 20C we have represented the voltage at the beginning of the current cycle as A. Notice that the voltage is at its maximum value because the rate of change of current as shown on curve A is at its maximum value at point A.

As the current in the circuit increases from A to B, the rate at which it is changing decreases. This means that the voltage induced in the coil will decrease until the current cycle has reached point B on curve A, and the voltage will have reached point B on curve C. Finally, when the current shown on curve A reaches point C where its rate of change has dropped to 0, the voltage will have dropped to point C on curve C and since the rate of change of current is 0 the voltage induced in the coil will be 0.

At point C on the current curve, the current begins to decrease in value. The rate at which it decreases begins to increase from point C to point D and reaches its maximum value at point E. Since the current is decreasing, the voltage induced in the coil will have the opposite polarity because it will try to prevent this decrease. It will reach maximum value at point E where the rate of current change is at a maximum. This is shown by the voltage waveform between points C, D and E on curve C. From point E to point G the current is still changing in the same direction, but its rate of change is decreasing from E to F until finally when it reaches G, its rate of change is 0. The voltage induced in the coil is represented by the portion of the curve between point E, F and G on curve C. Notice that once again when the current wave has reached point G where its rate of change is 0, the voltage waveform will also be at G. Notice that it is the rate of change of current which controls the voltage induced in the coil, not the actual value of the current flowing in the coil.

From point G to I on the current waveform shown in Fig. 20A, the current begins to change and the rate of change increases until it reaches its maximum value at point I. The voltage waveform is shown at C and the amplitude of the voltage increases from point G where the rate of current change is 0 to the maximum value at point I where the rate of current change is at a maximum.

From examining curves A and C, we can see that the changes in current and voltage across the coil do not occur at the same instant. As a matter of fact, since the current waveform from A to I represents one complete cycle, from A to E and from E to I represents a half cycle. We also refer to this as 180°. (There are 360° in a circle and half a circle is 180°.) From point A to C is one quarter cycle as is from C to E, from E to G and from G to I. Notice that the voltage waveform is identical to the current waveform except that it is one quarter of a cycle ahead of the current waveform. In other words, as the current starts at point A to build up to a maximum value at point C, the voltage is already at its maximum value at point A and starts to drop to its minimum value at point C. During the next quarter cycle when the current drops from its maximum value with one polarity at point C to point E, the voltage is ahead of it by one quarter of a cycle and goes from 0 to its maximum value with the opposite polarity at point E. We say that the current and voltage are out of phase. We refer to this as one quarter of a cycle or 90° phase difference. Since the voltage is ahead of the current we say that the voltage leads the current by 90° or one quarter cycle.

Summarizing what we have seen from Fig. 20, we notice that in the case of a resistance the voltage and current are in phase, but in the case of a coil the voltage leads the current by 90°. In any pure inductance, the voltage will always lead the current by 90° - this is an extremely important point; be sure that you remember it. We can also say that the current lags the voltage by 90° - this is the same thing as saying the voltage leads the current by 90°; the voltage is ahead of the current, therefore, the current must be behind or lagging the voltage.

Now what about the generator voltage - so far we have considered only the generator current. What is the phase relationship between the generator voltage and the generator current?

To simplify our problem let us assume that R has a resistance of 1000 ohms and that L has an inductive reactance of 1000 ohms. Therefore, any current flowing through R and through L will produce equal voltages across them. The voltage across the resistor will be IR and the voltage across the coil will be IX_L.

The waveforms in Fig. 20 tell us that the voltage across the coil is not in phase with the voltage across the resistance. This means that the two do not have their maximum values of voltage at the same instant nor do they have their minimum values at the same instant. Therefore, since the voltages are ac voltages and are not occurring at the same time, we can't simply add them together to find the total voltage across the two. For example, when the voltage across the resistor is at its maximum value as shown at point C and G in Fig. 20B, the voltage across the coil will be at 0. Similarly, when the voltage across the coil is at its maximum value as shown at point A, E and I in Fig. 20C, the voltage across the resistance is 0.

The relationship between the current, resistor voltage, coil voltage and generator voltages can be shown by means of a diagram called a vector diagram. The first step in drawing a vector diagram is to draw a vector to represent the current. We usually draw a horizontal line with an arrow on it and label it I to represent the current.

We know that the voltage across the resistor is in phase with the current and therefore we draw a vector E_R to represent the resistor voltage and this vector will fall on top of the current vector as shown in Fig. 21A. We can select any arbitrary length for this vector since we do not know the generator voltage or the current flowing in the circuit.

We know that the voltage across the coil will lead the current by 90°. Therefore, we draw another vector E_L which is rotated 90° counter-clockwise from the current vector as shown in Fig. 21A. Since the value of the resistance of R is equal to the inductive reactance of L, the voltage across the coil will be equal to the voltage across the resistor, therefore, we draw E_L the same length as E_R. The diagram shown in Fig. 21A represents the voltage across the resistor and the voltage across the coil.

To find the generator voltage we complete the vector diagram as shown in Fig. 21B. In this diagram we have drawn a dotted line from the end of the vector E_R parallel to vector E_L. We have drawn another dotted line from the end of vector E_L parallel to vector E_R. The point at which the two vectors intersect gives the value and phase relationship between E_G and I. Since E_L and E_R are equal, the angle between E_G and I will be a 45° angle, and the length of E_G will be 1.4 times the length of either E_L or E_R. This means that the generator voltage will be 1.4 times the voltage across either the coil or the voltage across the resistor.

Perhaps you noticed an apparent contradiction between what we have learned about the voltages in the circuit shown in Fig. 19 and Kirchhoff's Voltage Law. You will remember that Kirchhoff's Voltage Law stated that the sum of the voltage drop in a closed circuit is equal to the source voltage. If this is true for ac circuits then the voltage drop across R plus the voltage drop across L must be equal to the generator voltage. Yet in Fig. 21 we found that the generator voltage was only 1.4 times either E_R or E_L. At first glance you might think it should be twice E_R or E_L. However, remember that E_R and E_L are not in phase. This means that if you add these voltages at any instant their sum will be equal to the generator voltage.

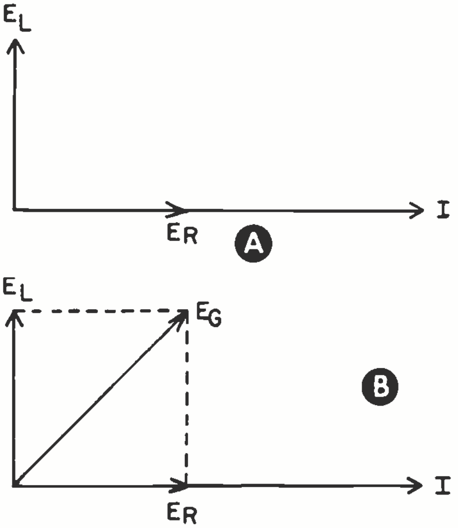


Fig. 21. Vector diagrams showing relationship between current, generator voltage, coil voltage and resistor voltage of the circuit shown in Fig. 19.

IMPEDANCE

In Fig. 19, we considered the coil as a pure inductance. We treated the resistance of the wire used to wind the coil as 0; the only opposition the coil offered was inductive reactance. Of course the wire will have resistance as well as certain other resistive effects to the ac current. The ac resistance of the coil is the sum of the resistance of the wire plus these other losses which increase the resistance. The impedance of the coil is the total opposition to current flow. It is made up of the opposition due to the inductive reactance of the coil and the opposition due to the ac resistance of the coil.

The practical way of studying how a coil behaves in an ac circuit is to consider the coil as being made up of a pure inductance with a resistor in series with it. This is essentially the type of circuit used in Fig. 19. Here you see that in the circuit the current lags behind the generator voltage. Where the resistance was equal to the inductive reactance, the phase difference was 45°. In actual practice, the resistance will usually be much smaller than the inductive reactance so that the phase difference will approach 90°. The higher the ratio of inductive reactance to resistance, the closer the phase difference will approach 90°.

In studying a complete circuit in which there is a coil and a resistance in the circuit, you can simply lump together the resistance of the resistor and the coil resistance and consider this the resistance in the circuit and then treat the inductance of the coil separately. However, if you are interested in finding the voltage across the coil, then you have to keep the resistance of the coil separated and use it with the inductive reactance of the coil since both will have an effect insofar as developing voltage across the coil is concerned.

FINDING THE CURRENT IN AN AC CIRCUIT

If you want to find the current flowing in this type of circuit when an ac voltage is applied, you must find the impedance of the circuit. The impedance is the total opposition to the ac current flow in the circuit.

There are several ways of finding the total flow of ac current in the circuit. We have already briefly started to introduce one in Fig. 21. We will go through this procedure in detail now and then show you another method. You may use whichever way is easier for you.

As an example, let us find the current flowing in the circuit shown in Fig. 22. Here we have a coil with an inductance of 2 henrys. This coil is connected in series with a 1000-ohm resistor. The two are connected across a 60-cycle generator having an output voltage of 500 volts. The resistance of the coil is so small, that compared to the 1000-ohms in the circuit, it is insignificant so we can ignore it. The problem is to find the current that will flow in the circuit.

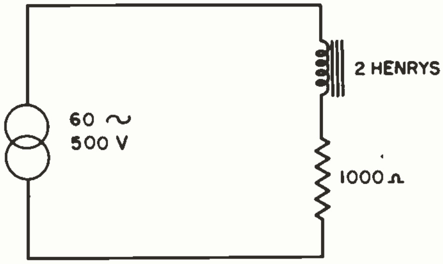


Fig. 22. There are two ways to find the current in the circuit shown above: by using vectors or by using a mathematical solution.

Vector Solution.

First, we must find the inductive reactance of the coil. To do this we use the formula:

$$X_L = 6.28 \times f \times L$$

and substituting 60 for f and 2 for L we get:

$$X_L = 6.28 \times 60 \times 2$$

which equals 753.6 ohms. Since this is a practical problem, we simply call it 750 ohms.

Now we know that the inductive reactance of the coil is 750 ohms and the resistance in the circuit is 1000 ohms. You might at first think that we can obtain the total opposition to the ac current flow simply by adding these two together. However, this is not true--you cannot simply add inductive reactance and resistance. Let us see why. We know that when voltage is applied to an inductance, the current that flows will be out of phase with the applied voltage. When voltage is applied to the resistance, the current that flows will be in phase with the applied voltage. The inductance and the resistance have different effects on current.

Adding the effect of the two together can be done by means of vectors.

You have already seen how vectors

can be used to indicate phase differences in quantities having the same frequency. Now we will see how they can be used to add similar quantities having the same frequency but a difference in phase.

As before, the angle between the vectors represents the phase difference between the quantities. The arrows are all drawn to the same scale, so that the length of the arrows indicates the amplitudes of the quantities to be added.

For example, suppose we wanted to show the relationship between two 60-cycle ac voltages A and B. A is 30 volts, and B is 40 volts, and they are 90° out of phase with each other.

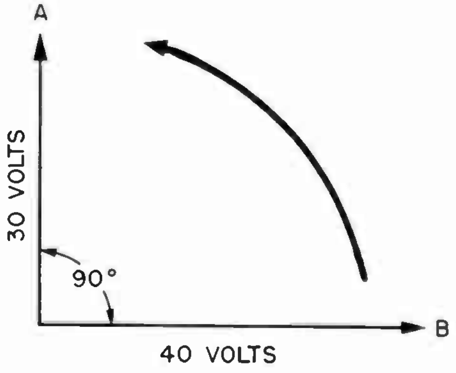


Fig. 23. In this diagram, the lengths of the arrows show the amount of voltage and the angle between them shows their phase relationship. They are considered to rotate counterclockwise.

A is leading B. Fig. 23 shows how we would draw this, using a scale of 1/2-inch equals 10 volts. We draw B 2 inches long, and we draw A, 1-1/2 inches long. Since A is leading B by 90°, we draw it 90° counterclockwise from B.

Now, suppose we wanted to find the sum of these voltages. We could not simply add 30 and 40, because of the difference in phase. This is where the vector diagrams will help us. We can add these two voltages, taking into account the phase difference as shown in Fig. 24. We say we are finding the "vector sum" of the two.

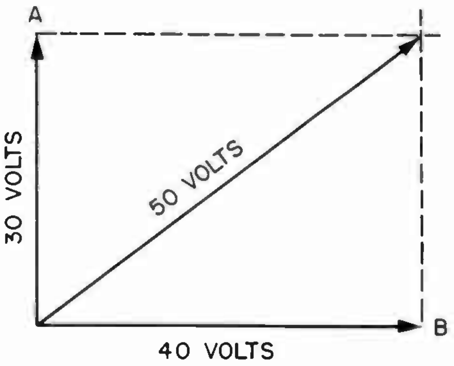


Fig. 24. How to find the vector sum of two ac voltages differing in phase.

To do this, we complete a rectangle by drawing lines parallel with the two vectors. Then we draw in a diagonal to the point where the two lines intersect. This diagonal represents the vector sum of voltages A and B. When we measure it, we see it is 2-1/2 inches long. Since we used the scale of 1/2 inch to 10 volts, we see that the vector sum is 50 volts.

Now let us see how we can apply this principle to find the total opposition or impedance in the circuit we have been studying. As we have already mentioned, when considering phase in a circuit, the phase of the current is always used as a reference. The current vector is drawn horizontally and pointing to the right, and voltage vectors are drawn in the positions corresponding to their phase relationship to the current. So the first thing we do is to draw an arrow to represent the current, as

Fig. 25. The current vector is drawn horizontally and used as a reference point for the other vectors.

shown in Fig. 25. We do not know what the current is, so its length does not matter, but we do know it should be drawn horizontally and pointing to the right. The next step in our procedure depends upon an important fact--that the voltage across the resistor will be in direct proportion to its resistance. We also know that the voltage across the resistor will be in phase with the current, and the voltage across the coil will be 90° ahead of the current. Therefore, we can draw two vectors, one on top of the current vector to represent the voltage across the resistor, and one 90° ahead of (counterclockwise from) the current vector to represent the voltage across the coil. We do not know what these voltages are, but since the voltage is in direct proportion to the resistance and reactance, we can draw the arrows using a scale that is in proportion to the ohmic values of the resistance and reactance and label the vectors R and X_L.

Fig. 26. The voltage across a resistor is in phase with the current, so the vector for the resistor voltage is drawn on top of the current vector.

First we draw a vector to represent the voltage across the resistance. If we use the scale of an inch to 500 ohms, the vector representing the voltage across the resistor will be 2 inches long. Since the current flowing through the resistor will be in phase with the voltage, we draw the resistance voltage vector and mark it R as shown in Fig. 26. Here you should notice that it is drawn right on top of the current vector. The current vector is not drawn to scale, but the resistance voltage vector is drawn 2 inches long.

Next, we draw the vector for the voltage drop across the coil. Since we have a reactance of 750 ohms, this vector should be 1-1/2 inches long. Since the coil voltage is 90 degrees out of phase with the resistor voltage, this vector is drawn as shown in Fig. 27 and labeled X_L. Now we have a vector diagram that represents the voltage across the resistance and the reactance in the circuit shown in Fig. 22. To get the impedance, we draw dotted lines as shown in Fig. 28 to complete the rectangle. The vector representing the voltage across the impedance is drawn in as shown in Fig. 28 to the point where these lines meet, and the impedance is obtained by measuring the length of this vector. On the diagram we have drawn, the impedance voltage vector is 2-1/2 inches long. Since we have used the scale of 500 ohms to the inch, the impedance in the circuit must be 2-1/2 times this value, or 1250 ohms. This is the total impedance or opposition to current flow in the circuit. Now that we have this figure, we can quickly determine the current that will flow.

To find the current we use Ohm's Law for coils. The current is equal to the voltage divided by the impedance. The letter Z is usually used to represent impedance. This can be expressed

$$I = \frac{E}{Z}$$

E=IZ

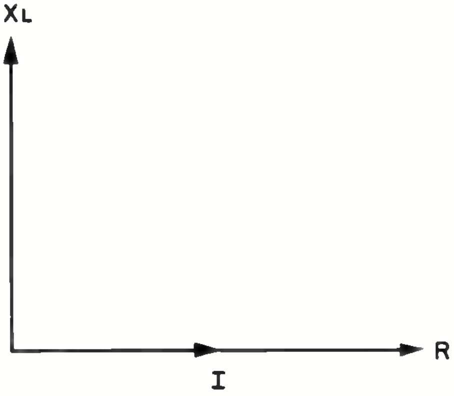


Fig. 27. The vector for the voltage across the inductance is drawn in at right angles to the resistor voltage vector.

Substituting 500 volts for E and 1250 ohms for Z we get:

$$I = \frac{500}{1250} = .4 \text{ amp}$$

Mathematical Solution.

Another method of solving for the impedance in an ac circuit is by means of the formula:

$$Z = \sqrt{R^2 + X_L^2}$$

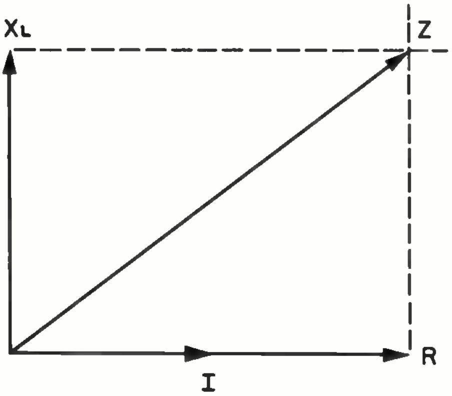


Fig. 28. The vector representing the voltage across the impedance is the vector sum of the other two.

The mathematical sign $\sqrt{}$ means to find the square root. Therefore, you square the resistance and the reactance, add the two together, and then take the square root of the sum. Once you have the impedance, proceed as before to get the current. Again, this is not the type of problem that the technician will have to solve, but it is important to remember the general method of obtaining the impedance in a circuit of this type. If you know how to do square root problems, the mathematical solution is the simpler; if you don't, the graphical solution is the one to use. It is particularly important to realize that you cannot obtain the impedance simply by adding the resistance and the reactance together. The impedance in a circuit will always be somewhat less than the sum of the two because of the difference in phase.

KIRCHHOFF'S VOLTAGE LAW

You will remember that Kirchhoff's voltage law stated that the sum of the voltage drops in a complete circuit is equal to the source voltage. Now let's see how this applies to an ac circuit consisting of inductance and resistance.

Using the same example as before, we have already calculated the reactance of the coil at 750 ohms and we know the resistance of the resistor is 1000 ohms. We can use Ohm's Law in the form:

$$E = I \times R$$

to find the voltage drop across the resistor. In the case of the coil, the voltage drop is:

$$E = I \times X_L$$

To find the voltage drop across the coil, we simply multiply 750 by the current, which we have already determined as .4 amp. 750 × .4 = 300. Therefore the voltage across the coil is 300 volts. The voltage across the resistor is 1000 ×.4 = 400 volts. Now look at Fig. 29 where we have indicated the voltages. We have 300 volts across the coil and 400 volts across the resistor, but our source voltage is only 500 volts. These are the readings we would actually obtain if we had meters connected as shown!

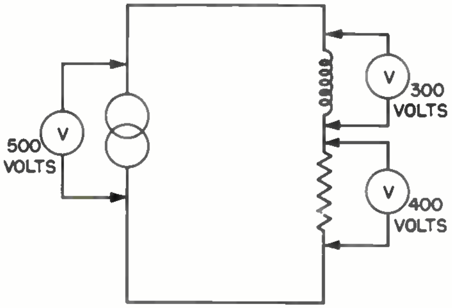


Fig. 29. With a source voltage of 500 volts, we have 300 volts across the coil, and 400 volts across the resistor, but they are not in phase.

This may appear to be a contradiction of Kirchhoff's Voltage Law, but actually it is not. You must remember that the voltage across the resistor will be in phase with the current, but the voltage across the coil will not be in phase with the current flowing through it. The voltages that we have just determined are effective voltages. At any given instant the sum of the voltage across the coil plus the voltage across the resistor will be equal to the voltage across the generator. However, the effective voltage across the coil and the resistor if they are simply added together would give us more than 500 volts.

To add these two voltages we must again resort to vectors. The vector addition of these two voltages using a scale of 200 volts equals 1 inch is shown in Fig. 30. Notice that the vector representing the voltage across the resistor is drawn 2 inches long, and the one representing the voltage across the coil is drawn 1-1/2 inches long. When we complete the vector diagram to find the sum, as before, we obtain a vector which is equal to the generator voltage of 500 volts.

The mathematical solution that we used before can also be used to obtain the source voltage. If we let the symbol E_G equal the source voltage we have:

$$E_G = \sqrt{E_R^2 + E_L^2}$$

If we substitute 400 for E_R, E_R^2 equals 160,000. Similarly E_L squared equals 90,000. Adding the two together we get 250,000; the square root of 250,000 is 500, so as before we find that $E_G = 500$ volts.

Importance of Phase.

A general knowledge of phase and vector diagrams helps you to understand the action of coils and capacitors in ac circuits and will make you a better-than-average technician. You will understand why you do certain things when making adjustments or repairs instead of just blindly following instructions. It is the men who know the "How" and the "Why" who command the highest salaries in the modern world of electronics.

Later in your course, you will learn that the opposition of a coil, which we have called inductive reactance, can be balanced or cancelled by the opposition of a capaci-

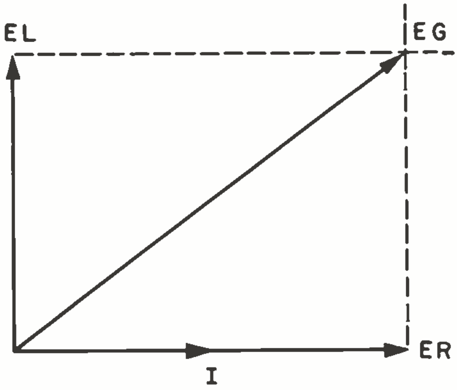


Fig. 30. Finding the vector sum of ER and EL.

tor, which is called capacitive reactance, because the two are of opposite phase. You will see the importance of phase in many other practical examples. Phase, however, is not a subject you can grasp in one lesson; you will understand it better and better with each succeeding lesson.

Q OF A COIL

We mentioned that since a coil is wound of wire and wire has resistance, there is no such thing as a perfect inductance. All coils have both inductance and resistance.

As you might expect, when manufacturers make a coil, they usually try to keep the resistance as low as possible. Generally, the lower the resistance is in proportion to the inductive reactance of a coil, the better the coil. The relationship between inductive reactance and resistance is called the Q of the coil. This is represented by the formula:

$$Q = \frac{X_L}{R}$$

A high-Q coil is a coil in which the value of the inductive reactance is much higher than that of the resistance. Coils with a Q of 100 or more are quite common.

Since the reactance of a coil increases with frequency, you might expect the Q to increase with frequency. This is true up to a certain point, but R is the ac resistance of a coil and it increases with frequency also. As long as X_L increases with frequency faster than R, the Q of the coil will increase, but if R increases faster than X_L, the Q of the coil will decrease as the frequency increases so the coil cannot be used at high frequencies.

Q is particularly important in tuned circuits when coils are used with capacitors. You will see why this is so later when you study these circuits.

SUMMARY

This section of your lesson is almost too important to try to summarize. However, to help you to review, here are the important things you should understand.

You should have a general understanding of what we mean by phase. When the current in an ac circuit is increasing exactly in step with the voltage, and reaches the maximum value at the same time as the voltage reaches the maximum value and reaches its minimum value at the same time as the voltage reaches its minimum value, we say that the current and voltage are in phase. In a circuit consisting of a pure inductance the current will lag the voltage by 90 degrees. This means that it is one-quarter of a cycle behind the voltage.

Impedance is the vector sum of resistance and reactance. The impedance in a circuit will be greater than the resistance or the reactance alone. Impedance cannot be determined simply by adding the resistance and the reactance.

The voltage across a component in an ac circuit can be found by Ohm's Law. The sum of the individual voltage drops in an ac circuit is equal to the source voltage, providing we add these voltages vectorially. We cannot add them by means of simple arithmetic and expect their sum to be equal to the source voltage. If we could measure the source voltage and the voltage across each of the parts in the circuit at any instant, we would find that the sum of the voltage drops at that instant would be equal to the source voltage.

SELF-TEST QUESTIONS

(ak) What do we mean when we say that the voltage and current in a circuit are in phase?

(al) What is the phase relationship between the voltage and current across a resistor?

(am) What is the phase relationship between the voltage and current across a coil?

(an) At what point in an ac cycle is the current changing at its maximum rate?

(ao) What is meant by impedance?

(ap) An ac generator with an output voltage of 250 volts is connected across a 1.5-henry coil and a 900-ohm resistor in series. The frequency of the generator is 100 cycles. Find the current flowing in the circuit.

(aq) In the preceding problem, find the voltage across the coil and the voltage across the resistor.

LOOKING AHEAD

You have now finished the study of the basic facts of resistors and coils. When you complete a similar study of capacitors in the next lesson, you will have a basic knowledge of these three important parts. In a later lesson you will learn more about how these three parts work together and what effect they have on ac signals. Remember that the ac supplied by the power company, audio signals, and radio frequency signals are all ac signals differing only in frequency and in some cases in wave shape. The important facts you learned about ac and coils in this lesson apply to all ac signals regardless of their frequency.

Most students are anxious to go ahead as quickly as possible with their course, particularly in the early lessons. However, do not be so anxious to go ahead with later lessons that you leave the earlier lessons without completely understanding them. The information given in these early lessons is basic and is information that you will use over and over again in more advanced lessons. If you do not understand how basic parts such as resistors, coils, and capacitors affect circuit performance, you will not be able to understand some of the later lessons.

ANSWERS TO SELF-TEST QUESTIONS

(a) Magnetic lines of force form complete loops.

(b) Near the coil.

(c) An air-core coil. The cardboard form merely supports the turns of the coil; it has no appreciable effect on the operation of the coil.

(d) Laminations are thin strips of iron or steel used to produce an iron core for a choke or transformer.

(e) An iron core provides a better path for the magnetic lines of force. We say it has a lower reluctance.

(f) Magnetomotive force is the force that sends magnetic flux around a magnetic circuit.

(g) The ampere-turn.

(h) 50 ampere - turns.

(i) Reluctance is the opposition to flux in a magnetic circuit. It is the equivalent of resistance in an electrical circuit.

(j) Yes. The reluctance in the magnetic circuit of an iron-core coil is much lower than the reluctance of the magnetic circuit in an air-core coil.

(k) They all have the same reluctance. Non-magnetic materials have the same reluctance as air.

(l) The permeability of a material indicates the ability of the material to pass the magnetic lines of force. The higher the permeability of the material, the less reluctance it will offer to magnetic lines of force.

(m) In a magnetic circuit the flux is equal to the magnetomotive force divided by the reluctance.

(n) A flux linkage is a magnetic line of flux cutting through a single turn of a coil. If the magnetic line of flux cuts through two turns then we have two flux linkages, and if it cuts through five turns then we have five flux linkages.

(o) Twelve. A magnetic line of flux cutting through a single coil produces one flux linkage. Therefore three lines cutting through four turns produces 3 × 4 = 12 flux linkages.

(p) Zero. If the number of flux linkages cutting a coil does not change, there will be no voltage induced in the coil.

(q) The induced voltage will produce a current which will in itself produce a magnetic field which will oppose any change in flux linkages.

(r) It will aid the original lines of force. If the field is reduced, the induced voltage produced in the coil will cause a current to flow in such a direction that the magnetic field produced will tend to prevent the number of flux linkages from decreasing. In order to do this it must aid the original field.

(s) (1) cutting lines of force, (2) changing the reluctance (3) changing the coil current.

(t) The variable reluctance phono pickup. In this type of pickup the needle moves between two coils. As the needle follows the record groove it moves from side to side decreasing the air gap on one side so that the reluctance on that side decreases and the flux increases.

(u) The transformer. Varying ac applied to the primary of the transformer causes a varying current to flow. This current in turn causes a varying flux; the varying flux cutting the secondary induces a voltage in the secondary of the transformer.

(v) Inductance.

(w) A self-induced voltage is a voltage induced in a coil that is caused by a change in the current flowing through the coil. The changing current causes a change in magnetic flux. The change in magnetic flux produces a self-induced voltage which tends to produce a current which in turn will produce a magnetic field opposing the original change.

(x) It will oppose the applied voltage. The self-induced voltage will try to keep the current constant so that the flux will remain constant. To do this it must oppose the applied voltage.

(y) The henry is the unit of inductance.

(z) If the voltage induced in a coil is 1 volt when the strength of the current flowing through the coil changes at a rate of 1 ampere per second, the coil has an inductance of 1 henry.

(aa) (1) the number of turns on the coil, (2) the diameter of the coil, (3) the permeability of the core material.

(ab) The inductive reactance of a coil is the opposition the coil offers to the flow of ac through it due to the inductances of the coil.

(ac) The inductive reactance of a coil is measured in ohms.

(ad) 3768 ohms. To find the inductive reactance of a coil you use the formula:

$$X_L = 6.28 \times f \times L$$

and substituting 60 for f and 10 for L we have:

$$X_L = 6.28 \times 60 \times 10$$
$$X_L = 3768 \text{ ohms.}$$

(ae) When two coils are placed near each other so that the flux from one coil cuts through turns of the other coil, any change in the flux from one coil will induce a voltage in the other coil. We call this coupling between the two coils mutual inductance.

(af) 14 henrys. When two coils that

are not mutually coupled together are connected in series, the total inductance is simply the sum of the two inductances.

(ag) 11 henrys. To find the total inductance of the two coils we use the formula:

$$L_T = L1 + L2 + 2M$$

and substituting 4 henrys for L1 and 3 henrys for L2 and 2 henrys for M we get:

$$L_T = 4 + 3 + (2 \times 2)$$
$$L_T = 11 \text{ henrys.}$$

(ah) 9 henrys. To find the inductance of the two coils we use the formula:

$$L_T = L1 + L2 - 2M$$

and substituting 8 henrys for L1, 7 henrys for L2 and 3 henrys for M we get:

$$L_T = 8 + 7 - (2 \times 3)$$
$$L_T = 9 \text{ henrys.}$$

(ai) 2200 millihenrys. To convert henrys to millihenrys you just multiply by 1000 which is the same as moving the decimal point three places to the right. 2.2 × 1000 = 2200.

(aj) .0001 henry. To convert microhenrys to henrys you divide by 1,000,000 or move the decimal point six places to the left. Moving the decimal point six places to the left requires that we add three zeros to the left of 1 and then simply move the decimal point.

(ak) When we say that the voltage and current are in phase we mean that any change in voltage produces a corresponding change in current. In other words, an increase in voltage causes an instant increase in current or a decrease in voltage causes an instant decrease in current.

(al) The voltage and current across a resistor are in phase.

(am) The voltage across a coil will lead the current by 90°. Another way of expressing the same thing is to say that the current lags the voltage by 90°.

(an) The current is changing at its maximum rate when the current wave is going through 0.

(ao) Impedance is the total opposition to current flow. It is made up of the reactive opposition and the resistive opposition to current flow.

(ap) $X_L = 6.28 \times 100 \times 1.5$
$= 942.0$ ohms

$$Z = \sqrt{R^2 + X_L^2}$$
$$= \sqrt{900^2 + 942^2}$$
$$= \sqrt{810,000 + 887,364}$$
$$= \sqrt{1,697,364}$$

$= 1303 \text{ ohms}$

$$I = \frac{E}{Z} = \frac{250}{1303} = .19 \text{ amps}$$

(aq) $E_R = IR$

$= .19 \times 900 = 171 \text{ volts}$

$E_L = IX_L$

$= .19 \times 942 = 179 \text{ volts}$

Lesson Questions

Be sure to number your Answer Sheet B106.

Place your Student Number on every Answer Sheet.

1. If the reluctance of a magnetic circuit is increased, what will happen to the flux?

2. If the number of flux linkages cutting a coil decreases, a voltage will be induced in the coil that will cause a current to flow, which will produce magnetic flux that will tend to prevent the original flux from decreasing. Is this statement true or false?

3. Explain what inductive reactance is.

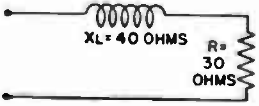
4. What is the inductive reactance of a 1-henry coil at a frequency of 100 cycles?

5. If two 15-henry coils have a mutual inductance of 5 henrys, what is the total inductance when they are connected in series if the flux of one coil aids the flux of the other?

6. Explain what is meant when we say "the voltage and current are out of phase."

7. What do we mean by the impedance of a circuit?

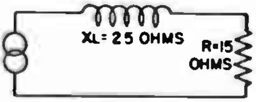
8. What is the impedance of the circuit shown?



9. If the frequency of a voltage source connected to a circuit consisting of a coil and resistor in series is increased, will the current flowing in the circuit increase, decrease, or remain the same?

10. If the current flowing in the circuit shown is 1 amp, find:

    (1) the voltage across the coil
    (2) the voltage across the resistor.



SINCERE APPRECIATION PAYS

Have you ever watched a dog respond to a friendly pat as a reward for obedience? Have you noticed how a child glows with joy when praised for good behavior? Have you ever felt your own brain cells respond with increased effort when you praise them by saying, "That's a fine piece of work, even if I did do it myself!"

Yes, everyone responds to sincere and merited praise. It is a tonic to both giver and receiver. It brings greater praise and appreciation back to you. It costs nothing more than a smile and a few sincere words, but it can truly achieve miracles in happiness and success, and put real money in your pocket.

Time spent in figuring how to give sincere and deserved praise is well worth while. Let people know that you appreciate their fine work, and watch the breaks come your way.

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ACHIEVEMENT THROUGH ELECTRONICS

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HOW CAPACITORS ARE USED

B107

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HOW CAPACITORS ARE USED

B107

STUDY SCHEDULE

By dividing your study into the steps given below, you can get the most out of this part of your NRI Course in the shortest possible time. Check off each step when you finish it.

☐ 1. **Introduction** .... **Pages 1 - 3**
This section gives a brief picture of what a capacitor is and the different types in use.

☐ 2. **How Capacitors Store Electricity** .... **Pages 4 - 12**
You learn about charging a capacitor, the factors affecting capacity, and the voltage rating of capacitors.

☐ 3. **Typical Capacitors** .... **Pages 13 - 23**
You study variable capacitors and paper, mica, ceramic, and electrolytic fixed capacitors.

☐ 4. **Capacitors in AC Circuits** .... **Pages 24 - 28**
You learn how ac flows in capacitive circuits, and you study the effect of connecting capacitors in series and in parallel.

☐ 5. **Simple R-C Circuits** .... **Pages 29 - 36**
Here we take up time-constants, phase, voltage distribution, and impedance in resistor-capacitor circuits.

☐ 6. **Answers to Self-Test Questions** .... **Pages 36 - 40**

☐ 7. **Answer the Lesson Questions.**

☐ 8. **Start Studying the Next Lesson.**

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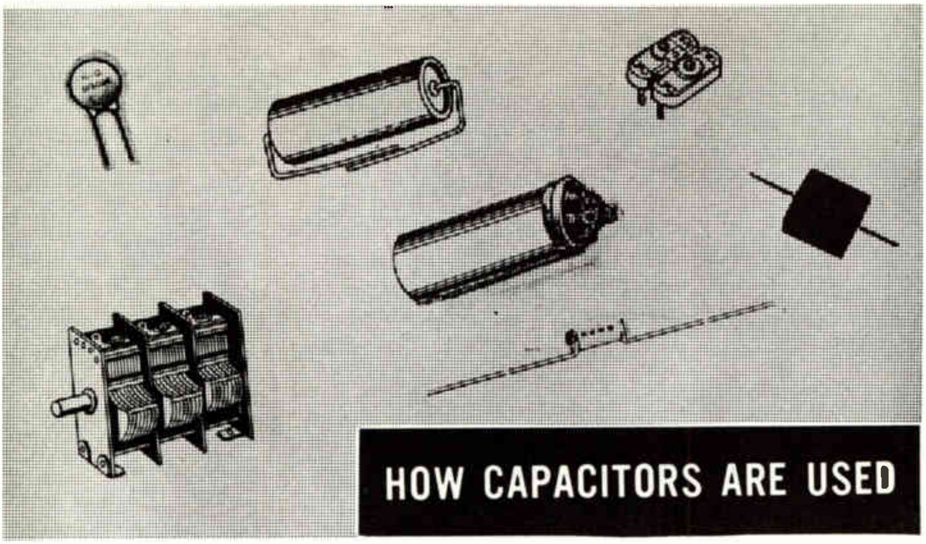


HOW CAPACITORS ARE USED

Of the three major electronic circuit parts, resistors, coils and capacitors, it would be impossible to pick the one that is the most essential. All three parts are extremely important. In many circuits all three are used together; in some circuits two of the three are used together. When used in combination, these parts are able to perform jobs that one cannot do alone.

In the preceding two lessons, you studied resistors and coils. In this lesson you will study capacitors in detail. After you have completed this lesson, you should have a good understanding of how these three basic parts work. Later, you will see how they are used together.

In many respects a capacitor is the opposite of a coil. You will remember that in an ac circuit with a coil in it, the current flowing in the circuit will lag or follow the applied voltage by 90 degrees. If instead of a coil we put a capacitor in the circuit, the current would lead the voltage by 90 degrees; in other words we would have just exactly the opposite effect. You will see more of this later in this lesson and also find out exactly why it is that in a capacitive circuit the current leads the voltage. For the present, let's start this lesson by learning a little about what a capacitor is and some of the fundamentals of how it works.

WHAT IS A CAPACITOR?

In its simplest form, a capacitor, or condenser, as many old-timers call it, consists of nothing more than two pieces of metal separated either by air or by some other nonconducting material placed between them. The material between the two plates, whether it is air, a liquid, or a solid, is called the dielectric. If there is nothing between the plates but air, we say the capacitor has an air dielectric.

The electrical size of a capacitor is called its capacity. A large ca-

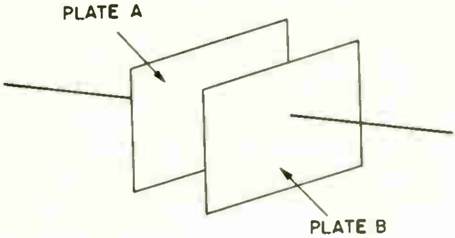


Fig. 1. A simple capacitor is nothing but two pieces of metal separated from each other.

pacitor has a large capacity. There are a number of things that affect the capacity of a capacitor, which you will study in a little while.

HOW A CAPACITOR WORKS

A simple capacitor made of two metal plates with an air dielectric between them is shown in Fig. 1. To see how a capacitor works, let's see what will happen when we connect this capacitor to a battery as shown in Fig. 2.

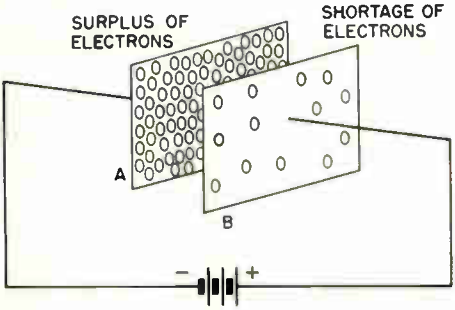


Fig. 2. When a capacitor is connected to a battery, a surplus of electrons is accumulated on one plate. This forces electrons off the other plate, leaving it with a positive charge.

When the plates of the capacitor are connected to the battery, electrons flow from the negative terminal of the battery into the plate of the capacitor connected to the negative terminal. There will be a surplus of electrons built up on this plate of the capacitor.

You know that one of the characteristics of an electron is that it repels other electrons. Remember the rule of charges, like charges repel. Therefore, the surplus electrons on the one plate of the capacitor will repel electrons from the other plate back to the positive terminal of the battery. At the same time, the positive terminal of the battery attracts electrons and pulls them from the plate connected to it, leaving a shortage of electrons on this plate, giving it a positive charge. This positive charge will attract electrons from the negative terminal of the battery to the plate connected to it. Thus, there will be a surplus of electrons on one plate and a shortage of electrons on the other. The electron flow will continue until plate A is just as negative as the negative battery terminal, and plate B is just as positive as the positive battery terminal. When this condition exists we say the capacitor is charged.

If we suddenly disconnect the capacitor from the battery, the condition of unbalance that has been set up on the capacitor plates will remain. We will have a surplus of electrons on one plate and a shortage of electrons on the other. Thus, we have electricity stored in the capacitor.

You will remember that one of the characteristics of a charged object is that it tries to give up its charge in order to become neutral as quickly as possible. Therefore, if we connect a wire from one plate of a capacitor to the other, the electrons will flow from the side having a surplus of electrons over to the side having a shortage of electrons until the number of electrons on the two plates is balanced, and there is no longer a charge on them.

This is a very brief explanation of how a capacitor works, how it is charged, and how it can store electricity. We will look into this more thoroughly in the next section of this lesson, but this is enough to give you a general idea of how a capacitor works. Keep in mind that a capacitor can store electricity. Before touching the leads of a large capacitor you should short the leads together with a screwdriver or similar object to be sure the capacitor is discharged, otherwise you may discharge the capacitor and receive an unpleasant and possibly dangerous shock!

TYPES OF CAPACITORS

Capacitors can be divided into two types, according to what type of material (called the dielectric) separates the plates. One type has an air dielectric, and the other has a solid or liquid dielectric. When we say a capacitor has an air dielectric, we simply mean that there is nothing but air between the plates of the capacitor. When we say a capacitor has a solid or liquid dielectric we mean that some insulating material other than air has been inserted between the plates.

You will see typical examples of all these types of capacitors later; you will learn more about them, what they look like, and where they are used in electronic circuits; but first let us learn more about how they work.

How Capacitors Store Electricity

In considering a capacitor, you may at first wonder how a capacitor can be used in an electronic circuit because there is no complete circuit through the capacitor. In the sketch of the simple capacitor shown in Fig. 1 you can see that the two plates of the capacitor do not touch each other. There is a space between the two plates so that the electrons on one plate cannot normally flow from one plate to the other.

When we connected a battery to a capacitor we saw that the plates of the capacitor became charged, one plate picking up a surplus of electrons and the other losing electrons so that it had a shortage.

The usefulness of a capacitor depends upon its ability to store electricity or to hold a charge. Let's learn a little more about how a capacitor is charged, so we can better understand some of its more important uses.

CHARGING A CAPACITOR

A capacitor cannot be charged instantly. It takes time for the charge to build up after the electrons start to flow from the negative terminal of the battery into one plate of the capacitor and from the other plate to the positive terminal of the battery. The length of time that it takes depends upon two things, the size of the capacitor and the amount of resistance in the circuit.

You might think that there was no resistance in the circuit we have shown in Fig. 2. However, this is not the case. There is resistance in the leads used to connect the capacitor to the battery, and in addition there is the internal resistance of the battery itself. These two resistances will limit the rate at which the capacitor can charge.

Because it does take some time to charge a capacitor, there will be a current flowing in the circuit shown in Fig. 2 when the capacitor is first connected to the battery. This current will flow as long as the battery is charging the capacitor. The longer it takes the battery to charge the capacitor the longer there will be a current flowing in the circuit. Therefore, you can see that even though the electrons cannot cross from one plate of the capacitor to the other plate there is a current flow in the circuit, at least for the short time it takes to charge the capacitor.

A question that sometimes comes up when considering a charged capacitor is whether or not the capacitor has any more electrons than it has in the discharged state. The answer to this question is no--the capacitor will have the same number of electrons whether it is charged or discharged. The only difference is that when a capacitor is discharged there is no charge on any of the atoms making up the metal on either plate. In other words, each atom has enough electrons to exactly neutralize the charge in its nucleus. However, when the capacitor is charged, some of the electrons are moved off one plate so there is a shortage of electrons on that plate, and the same number of extra electrons are forced onto the other plate, so there is a surplus of electrons on it. Thus the total number of electrons in the material making up the capacitor does not change.

The Amount of Charge.

The charge on a capacitor depends upon the battery voltage used to move electrons onto one plate and away from the other. A battery with a higher voltage can exert more force on the atoms making up the capacitor plates and thus move more electrons than a battery with a lower voltage could. However, there are other things that affect the charge we can store in a capacitor. The electrical size of the capacitor is just as important as the charging voltage. The electrical size of the capacitor is called the capacity of the capacitor. Now let's see what we mean by capacity.

CAPACITY

The term capacity is used to describe the electrical size of a capacitor. It is used in the same way as inductance is used to describe the electrical size of a coil, and resistance is used to indicate the electrical size of a resistor.

Just as the henry is the unit of inductance and the ohm is the unit of resistance, the "farad" (pronounced FAIR-ad) is the unit of capacity. It was named after the scientist Michael Faraday, who did a great deal of the early work with capacitors. The capacity of a capacitor is a measure of its ability to store electricity. A capacitor with a high capacity can store more electrons than a capacitor with a lower capacity. Thus the capacity of a capacitor indicates its electrical size to the technician just as the resistance of a resistor indicates the electrical size of the resistor.

We can express the capacity of a capacitor in terms of charge and voltage. The capacity of a capacitor is equal to the charge it will take divided by the voltage used to put that charge on the capacitor. The amount of charge is expressed in units called "coulombs." A coulomb represents a certain quantity of electrons. If a current of 1 ampere flows in a circuit for one second, the number of electrons moving past a given point in the circuit represents one coulomb of electricity. If when we connect a one-volt battery across a capacitor we can store a charge of 1 coulomb in the capacitor, its capacity is 1 farad. If the capacitor would take a charge of 2 coulombs with an applied voltage of 1 volt, the capacity would be two farads. The farad actually represents an extremely large capacity. It is so large in fact that it is never used in electronics. Let us look at the smaller units of capacity that are used.

Units of Capacity.

Since the farad is so large a unit, capacity in electronic circuits is usually expressed in smaller units, which are fractions of a farad. They are:

1. The microfarad, which is equal to one-millionth of a farad. Microfarads are abbreviated in several ways; the most common abbreviations are μf, mf, and mfd.

2. The picofarad, which is equal to 1-millionth of a microfarad. It

is abbreviated pf. In addition to the picofarad you will also run into the micro-microfarad, which is also equal to 1-millionth of a microfarad. The micro-microfarad was used for many years to designate a millionth of a microfarad, but in recent years the picofarad has replaced it. If you should be looking at a diagram of a modern radio or TV receiver the chances are you'll find that the abbreviation pf has been used to indicate picofarads but if you are working on an older set then you will find micro-microfarad used. The abbreviations used for micro-microfarad are µµf, mmf, and mmfd.

Because all seven abbreviations are frequently found in electronics, you should learn them all. The Greek letter µ is the Greek letter "mu" which is pronounced MEW.

You should have no difficulty in remembering that the prefix micro means one millionth, because you have run into this several times previously. The microfarad is simply one millionth of a farad. Actually, you will not be dealing with farads at all because this is such a large unit and for practical purposes you can consider that the unit of capacity in electronics is the microfarad. The smaller unit, which you will have to deal with, is the picofarad, which is a millionth of a microfarad.

Sometimes it is necessary to change from microfarads to picofarads and vice-versa. To change from microfarads to picofarads, you simply multiply by one million or move the decimal point six places to the right. In other words, a capacitor that has a capacity of 5 microfarads has a capacity of 5,000,000 picofarads. You simply add six zeros. A capacitor that has a capacity of .0005 microfarads has a capacity of 500 picofarads. You simply move the decimal point six places to the right.

To convert from picofarads to microfarads you divide by one million, and this can be done by moving the decimal point six places to the left. To do this, you can add zeros to the left. Thus 100 picofarads can be written 000,000,100 picofarads. All the zeros to the left of the 1 have no meaning. To convert this value to microfarads, move the decimal point six places to the left and you get 000.0001 microfarad. The zeros preceding the decimal point have no meaning, so they can be dropped, and you have .0001 microfarad or .0001 mfd.

Since the micro-microfarad is also equal to one millionth of a microfarad - in other words it is equal to a picofarad - if you should run into an older receiver where the values are given in micro-microfarads and you want to convert the value to microfarads you use exactly the same procedure as used in converting picofarads to microfarads.

No doubt as you are reading the preceding section you noticed how long the words microfarad and picofarad are. Technicians have shortened these words. The word microfarad is frequently abbreviated to "mike". Thus if you went to a wholesaler to buy a 2-microfarad capacitor you would probably simply say, "I want a 2-mike capacitor". Technicians have shortened picofarad to simply the abbreviation pf. Thus if you were ordering a 100 picofarad capacitor you would probably order it as a 100-pf capacitor rather than pronouncing the entire word.

Another abbreviation is as follows: instead of saying decimal point, 0, 0, 1 microfarad to identify a .001 mfd capacitor technicians usually say "point double oh one mike". Similarly for .00025 mfd they would say "point triple oh two five mike".

FACTORS AFFECTING CAPACITY

If you have ever looked into tne back of a radio receiver you have probably noticed what we call a variable capacitor. A variable capacitor consists of a set of fixed plates and a set of plates that can be rotated. As the receiver is tuned across the broadcast band the rotating plates will move into position and mesh between the fixed plates. The actual capacitor in the receiver might have been made of two or three separate capacitors all connected together so that the rotating plates all rotate at the same time. A capacitor with two sections is called a 2-gang capacitor and one with three sections is called a 3-gang capacitor. This type of capacitor is called a variable capacitor because its capacity is varied as you rotate the movable plates and mesh them between the stationary plates. When the plates are completely meshed the capacitor has its maximum capacity and when they are rotated so that they are separated as far as possible the capacitor has its minimum capacity.

There are a number of factors that affect the capacity of a capacitor. So you will understand how the capacity of a variable capacitor is changed and also help you to understand the other capacitors you will encounter in electronics work, we will now discuss some of the factors affecting capacity.

1. Area of Plates.

The capacity of a capacitor depends upon the area of the plates. Thus, if the area of each plate of a simple capacitor such as the one shown in Fig. 1 is doubled, the capacity would be doubled.

There are other ways in which the area can be increased in order to increase the capacity. For example, look at the capacitor shown in Fig. 3A. Notice that instead of a simple capacitor made up of two plates as we had in Fig. 1, here we have three plates. Two of the plates, marked A1 and A2, are connected together. If we start off with a capacitor having the two plates A1 and B, and then add the plate A2 to the capacitor, we would double the capacity. You can see why this is so when you consider what happens to the area of the plates when we add plate A2. Let's assume that each plate has an area of one square inch. Thus the area of plate

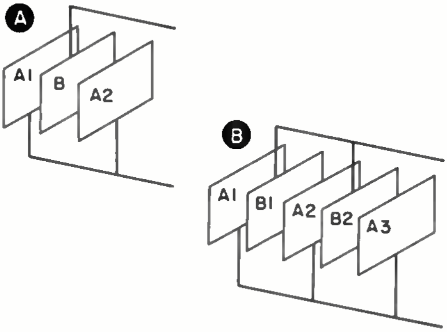


Fig. 3. Adding plates to a capacitor increases the capacity.

A1 opposite plate B is one square inch. When we add plate A2, we will have the areas of A1 and A2 exposed to both sides of B. Thus the effective area of the plates is doubled and therefore the capacity is doubled.

Additional plates can be added as shown in Fig. 3B. Adding additional plates to a capacitor actually increases the area of the plates, which in turn increases the capacity.

In considering the area of the plates, we must consider only the overlapping area. For example, if we have a capacitor made up of two plates each having an area of 1 square inch, and positioned as shown in Fig. 4A, we will have a certain capacity. However, if without changing the size of the plates we move them as shown in Fig. 4B, the capacity will be reduced, because the overlapping area of the plates is reduced. The part of plate A that is not directly opposite part of plate B will have little or no effect on the capacity. Similarly, the part of plate B that is not opposite part of plate A will have little or no effect.

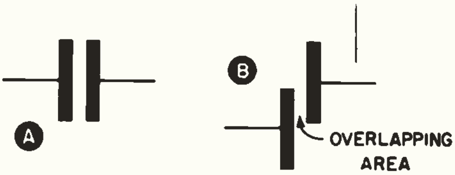


Fig. 4. Only the overlapping areas of the plates affect the capacity of a capacitor.

This is the principle that is used in variable capacitors. Here a number of plates are arranged so that one section of plates is movable and can be made to overlap more or less of the other section, thus exposing larger or smaller areas of the two sections to each other.

2. Spacing.

The distance between the plates of a capacitor will also affect the capacity. Capacity is inversely proportional to the spacing between plates. For example, if the spacing is reduced to one half, there will be twice the capacity. If it is reduced to one quarter, there will then be four times as much capacity. Also, if you double the space between the plates you will have one half of the capacity; if you triple the space you will have one third of the capacity. This is due to the fact that when the repelling effect of the electrons on one plate and the attracting force of the shortage of electrons on the other plate must act over a greater distance, they are not able to drive as many electrons out of the one plate of the capacitor and pull as many onto the other plate. As a result, the capacitor is not able to store as great a charge. You already know that the capacity of a capacitor is equal to the charge in coulombs divided by the voltage required to give that charge. Thus, if the charge a capacitor can hold is reduced, the capacity will go down. Moving the plates farther apart will reduce the charge that you can get on a capacitor for a given applied voltage. Conversely, bringing the plates closer together will increase the charge you can get on a capacitor for a given applied voltage.

3. Dielectric.

We have already mentioned that the type of dielectric used between the plates of the capacitor has an effect on the capacity. If instead of air between the plates we place a piece of mica, paper, or ceramic material, the capacity will be increased. As a matter of fact, if we slide a piece of mica between the plates of a capacitor so that the mica exactly fills up the space we will find that the capacity will increase somewhere between 6 and 8 times.

DIELECTRIC CONSTANT

In the preceding section we mentioned that inserting a piece of mica between the plates of a capacitor would increase the capacity somewhere between 6 and 8 times. The amount that a certain material will increase the capacity when used as a dielectric, compared to the capacity when air is used, is called the "dielectric constant" of the material. In other words, the dielectric constant tells us the number of times that the capacity will be increased by inserting a certain material between the plates of a capacitor. Actually, the dielectric constant is based on the number of times the capacity would be increased over the capacity we would have if the dielectric were a perfect vacuum. However, air between the plates affects the capacity very little. The capacity is practically the same with an air dielectric as it would be with a perfect vacuum between the plates so we say that the dielectric constant of air is 1; in other words it is the same as a vacuum between the two plates.

Different materials have different dielectric constants. Paper has a dielectric constant of somewhere between 1.5 and 3, depending upon the grade of paper. Mica has a dielectric constant between 6 and 8. Different types of oil have dielectric constants from about 2 up to about 10. The ceramic materials used in ceramic capacitors have a wide range of dielectric constants going up to as high as about 1500. You can see from this why it is possible to make ceramic capacitors with large capacities in small physical sizes.

We already mentioned that the effect of a dielectric is to increase the capacity of the capacitor. If there were a perfect vacuum between the plates of a capacitor, electrons flowing into one plate of the capacitor would place a negative charge on this plate and electrons flowing from the other plate would place a positive charge on it.

However when we place any dielectric material, which of course includes air, between the plates of the capacitor, the electrons on the negative plate of the capacitor distort the atoms of the material between the plates. Before the plates of the capacitor are charged, the atoms in the dielectric will be in their normal state with the electrons revolving around the nucleus as shown in Fig. 5A. However, when the electrons flow onto the negative plate of the capacitor, they will tend to repel the electrons in the dielectric. Since the dielectric is an insulator, the electrons are not free, but are bound to the atoms; however the repelling effect of the electrons on the negative plate will shift the path of the electrons in the dielectric so that the path around the nucleus will be like that shown in Fig. 5B. Notice that the electrons are pushed away from the negative plate and towards the positive plate. As these electrons move closer to the positive plate, they tend to repel the electrons

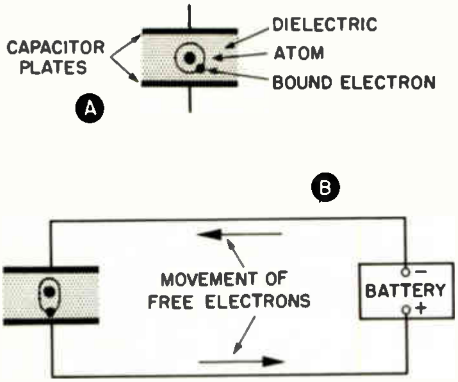


Fig. 5. Electrons in the dielectric are bound to their atoms, but their paths are shifted when a battery is connected across the capacitor, so that they come closer to the positive plate, thus transferring the effect of the extra electrons on the negative plate.

on the positive plate. Because the electrons from the atoms in the dielectric move over towards this plate of the capacitor, the dielectric has the effect of reducing the space between the plates. This places the negative charge very close to the positive plate and drives many more electrons off the positive plate of the capacitor than could be removed if the two plates were in a vacuum.

As we mentioned, air acts almost like a perfect vacuum. There is very little of this effect occurring when the dielectric is air. However, with materials of a higher dielectric constant this effect is more pronounced. This is particularly true in the case of ceramic materials where there is considerable distortion of the atoms in the dielectric so that the net effect is to get the same result as you would get by having the plates of the capacitor practically touching. Of course, in a practical case you can't have the plates practically touching, because they would probably short together and then the capacitor would be of no value. However, by using the right dielectric we get just as much capacity as we would with the plates practically touching and at the same time the dielectric between the plates holds the plates rigid and reduces the possibility of the plates accidentally shorting together.

VOLTAGE RATINGS

We mentioned previously that the charge that can be placed on a capacitor depends upon the electrical size or the capacity of the capacitor and also on the voltage used to place the charge on the capacitor. You might think from this that you could put more and more charge on a capacitor simply by increasing the voltage higher and higher. However, this is not the case because there is a limit to how much voltage can be applied to a capacitor.

Manufacturers design capacitors with a certain spacing between plates. If the plates are put very close together, you cannot put a very high voltage on the capacitor, because the electrons forced onto the one plate of the capacitor would jump right across the space between the plates to reach the other plate of the capacitor which has a shortage of electrons. Once this happens current will flow across the point where the capacitor breaks down, at least until you eliminate the short by shutting off the power. Sometimes when the electrons jump across the capacitor in this way the capacitor is permanently damaged.

Working Voltage.

When a manufacturer designs a capacitor he designs it for use in a circuit with a certain maximum operating voltage. The voltage is marked on the capacitor and is usually called the working voltage. The capacitors you will find in small pieces of electronic equipment such as radio and TV receivers will usually have a working voltage somewhere between 200 and 600 volts. Some of the capacitors in a TV receiver may have a working voltage as low as 200 volts. These capacitors are used in circuits where the operating voltage does not exceed 200 volts. Others used in higher voltage circuits may have a working voltage of 400 volts and still others used in circuits with an even higher voltage may have a working voltage of 600 volts or more.

One point to keep in mind when servicing electronic equipment is that the manufacturer of the equipment usually uses as low a working voltage as possible in order to keep the cost of the equipment low. However, there is no reason why a capacitor with a higher working voltage cannot be used providing there is room to do so.

Peak Voltage.

Sometimes you will find a capacitor with two voltage markings on it. It may be marked "working voltage 450 volts, peak voltage 525 volts". This type of marking is usually found on an electrolytic capacitor designed for use as a filter capacitor in a power supply. Here you know that the output of the rectifier in the power supply is pulsating dc. Thus the actual voltage at the output of the rectifier is not constant. If the dc output voltage from the power supply is 450 volts, during part of the time when the pulses from the rectifier tube reach their peak, the voltage will exceed this value. As long as this voltage peak does not exceed 525 volts, a capacitor marked with a 450-volt working voltage and a 525-volt peak voltage will work satisfactorily.

Some manufacturers do not mark electrolytic capacitors in this way. They simply mark them with the working voltage with the assumption that the peak voltage will not exceed a safe value.

SUMMARY

There are a number of important points that you should remember from this section of the lesson. First, remember that the basic action of a capacitor depends upon its ability to store an electric charge. Also remember that there is no complete circuit through a capacitor, but current will flow in a circuit in which a capacitor is connected while the capacitor is being charged and while it is being discharged. Remember that a capacitor is not charged instantly, but there is some time involved in charging a capacitor. The actual time it takes to charge a capacitor fully will depend upon the capacity and the resistance in the circuit.

Remember that the electrical size of a capacitor is measured in farads, but the farad is such a large unit that the practical values are the microfarad, which is a millionth of a farad, and the picofarad, which is a millionth of a microfarad.

The capacity of a capacitor depends upon the area of the plates, the spacing between the plates, and the dielectric between the plates.

The dielectric constant of the material is a number which tells you the number of times the capacity of a capacitor will be increased when this type of material is placed between the plates of the capacitor. Different materials have different dielectric constants; one of the highest is ceramic, which has a dielectric constant as high as 1500.

The voltage rating of a capacitor tells you the maximum safe voltage that you can apply to a capacitor. Capacitors having a higher voltage rating can always be used in replacing a defective capacitor in a piece of electronic equipment if there is room.

SELF-TEST QUESTIONS

(a) What do we mean when we say a capacitor is charged?
(b) What two factors affect the length of time it takes to charge a capacitor?
(c) Does a capacitor have any more electrons on its plates when it is charged than when it is discharged?
(d) What factor determines the amount of charge a capacitor can hold for a given applied voltage?
(e) What is the basic unit of capacity?
(f) What two practical units are used in electronics to indicate the capacity of a capacitor?
(g) Convert .0033 mfd to picofarads.
(h) Convert 680 pf to mfd.
(i) Name the three factors that affect the capacity of a capacitor.
(j) If you cut the spacing between the plates of a capacitor in half, will this double the capacity of the capacitor or will it cut the capacity of the capacitor in half?
(k) What is the dielectric constant of a material?
(l) What is the dielectric constant of air?
(m) What type of material has the highest dielectric constant?
(n) Why does a material with a dielectric constant greater than air have the effect of increasing the capacity of a capacitor?
(o) A capacitor is marked .02 microfarads, 400 volts; what does the marking 400 volts mean?

Typical Capacitors

Capacitors can be divided into two types, fixed capacitors and variable capacitors. A fixed capacitor is a capacitor which has a fixed capacity - in other words, the capacity of the capacitor cannot conveniently be varied. A variable capacitor, on the other hand, is a capacitor that is designed so that its capacity can be varied.

Capacitors can be further divided into types depending upon the dielectric material used. Most variable capacitors have an air dielectric and therefore are also referred to as air capacitors. Some variable capacitors have a mica dielectric and these are referred to as variable mica capacitors.

Most fixed capacitors use some dielectric other than air. Many capacitors use a paper dielectric and these are usually referred to as paper capacitors. Some capacitors of this type are dipped in a mylar coating to seal the capacitor and these are sometimes called paper mylar capacitors. Some fixed capacitors use a mica dielectric and these are called mica capacitors. Mica capacitors might also be sealed in a mylar case and these are sometimes called mylar-dipped mica capacitors.

Ceramic is widely used in capacitors as the dielectric and this type of capacitor is called a ceramic capacitor.

Large capacitors used in power supplies are called electrolytic capacitors. These capacitors use an electrolyte which forms a film that acts as the dielectric. You will study these capacitors in detail shortly and learn more about them at that time.

All capacitors, regardless of type, can store a charge. Of course, some capacitors can store more charge than others because they have a greater electrical size. In this section you will see that there is a reason for having these different types of capacitors, and also you will learn more about the common types of capacitors that you will encounter in electronics work.

VARIABLE CAPACITORS

A typical variable capacitor is shown in Fig. 6. This capacitor is actually two capacitors coupled by a common shaft, and as you know this type is called a two-gang capacitor. In some receivers you will find 3-gang capacitors, and in some old sets and in some communications

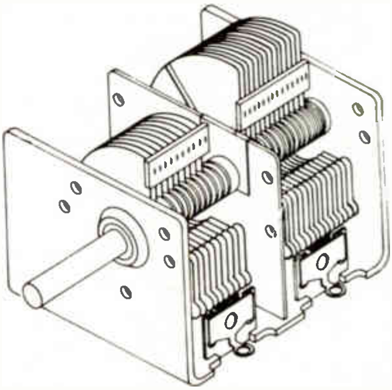


Fig. 6. A variable capacitor.

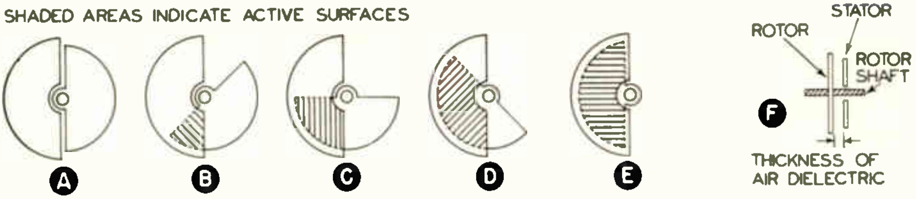


Fig. 7. How a variable capacitor with straight-line capacity plates works.

receivers you will find 4-gang capacitors. Sometimes all sections are identical; sometimes you will find that one section has smaller plates than the others.

Each section of a variable capacitor is made up of two sets of plates. The one set of plates that do not move are all connected together and insulated from the capacitor frame. These plates are called the stator plates, in other words, the stationary plates. The other set of plates are connected directly to the shaft and to the capacitor frame. These plates rotate and hence are called the rotor plates. Since these plates are connected directly to the capacitor shaft and to the frame, if you mount the capacitor on a metal chassis, the plates are automatically connected to the chassis. This does not present any problem, because in most circuits where a capacitor of this type is used, it is desirable to connect one set of plates to the chassis. The chassis acts as a ground or common connection for all rf (radio frequency) circuits.

There are two different types of plates found in variable capacitors. One type of plate is called the straight-line capacity type; the other is called the straight-line frequency type. An example of the straight-line capacity type of plate is shown in Fig. 7. Notice that in A of Fig. 7 the plates are completely separated so that the capacity is at a minimum. Actually there will be some capacity, because even though the plates are not meshed, the ends of the plates of the rotor have a certain capacity to the ends of the plates of the stator. In B the capacitor plates have been rotated through one eighth of a turn and the overlapping area of the two sets of plates is one quarter of the total area. We now have approximately one quarter of the total capacity. As the capacitor is turned another eighth of a turn, from position B to position C, so that it has completed a quarter turn, one-half of the area of the plates is overlapping and we have one half of the total capacity. Similarly, when the capacitor has been moved to three

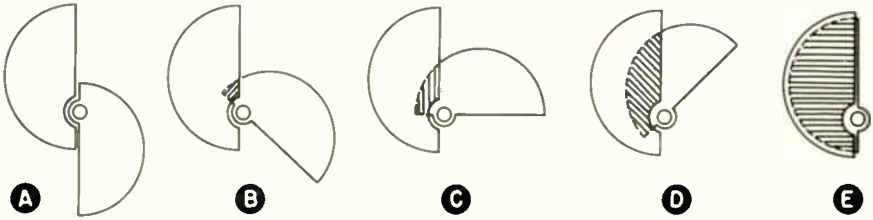


Fig. 8. How a variable capacitor with straight-line frequency plates works.

eighths of a turn, three-quarters of the area is overlapping and we have three quarters of the total capacity, and finally with a half turn the entire two areas are completely overlapping and we have maximum capacity.

There is another type of plate that is called the straight-line frequency type. Here the plates are shaped as shown in Fig. 8. Now when the plates are moved from position A to position B, less than a quarter of the area is overlapping even though the capacitor has gone through an eighth of a turn and we have less than a quarter of the total capacity.

Similarly when it is moved to position C, although the capacitor has been turned through a quarter of a turn, less than half of the two areas are overlapped and we will have less than half the total capacity. However, the increase in capacity obtained by rotating the capacitor from B to C is greater than was obtained in rotating it from A to B because the increase in overlapping area is greater. Similarly we get a still greater increase in capacity in going from C to D and an even greater increase in capacity in going from D to E.

The reason for this type of capacitor is that capacitors are used in conjunction with coils in the tuning circuits of radio and TV receivers, to select one station and reject others. For example, in a radio designed for the standard broadcast band you will find a coil and a capacitor used to select the desired station and reject the others. At the high end of the broadcast band it takes a smaller change in capacity to get a given frequency change than it does at the low end of the broadcast band. Therefore if you use the straight-line capacity type of capacitor, stations at the high-end frequency of the dial will be squeezed together and stations at the low-end frequency will be spread out. This makes it difficult to tune stations at the high frequency end of the dial. With the straight-line frequency type, however, the different frequencies are spread evenly across the dial of the receiver so that it is just as easy to tune in a station at the high end of the dial as one at the low end of the dial. Most modern broadcast receivers use the straight-line frequency type of capacitor because it is somewhat easier to tune the receiver.

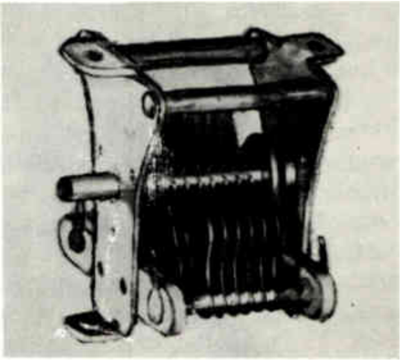


Fig. 9. A single-section variable capacitor of the transmitting type.

A single-section tuning capacitor such as might be found in a radio frequency transmitter or any other device where a variable capacitor is needed and high voltage is present is shown in Fig. 9. Notice that this capacitor is basically similar to one section of the capacitor shown in Fig. 6. The big difference is that the spacing between the plates is greater. The greater spacing is needed in high-voltage circuits to avoid arcing between the plates. Arcing is simply a flash-over that occurs where the voltage is so high that the electrons are able to jump from one plate of the capacitor to the other.

Trimmer Capacitors.

Trimmers are small variable capacitors, so called because they are used to trim or adjust resonant circuits whose main tuning capacitor is much larger.

Most ganged variable capacitors are equipped with trimmers so each ganged section can be individually adjusted. These trimmers use a mica dielectric, and the movable plate is of spring material which tends to stay away from the fixed plate, as shown in Fig. 10. A screw electrically insulated from the movable plate draws it closer to the fixed plate when tightened, thus increasing the capacity.

In some cases the trimmer is a miniature air dielectric capacitor, just like a single tuning capacitor.

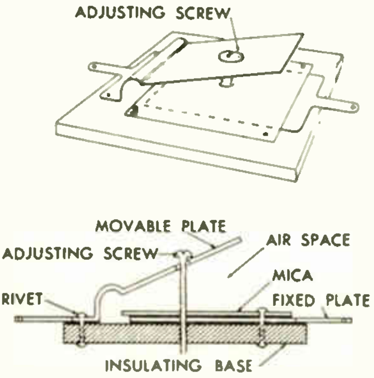


Fig. 10. A typical trimmer capacitor.

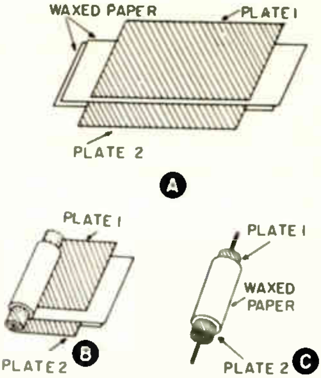


Fig. 11. How a paper capacitor is made.

PAPER CAPACITORS

A paper capacitor is made by taking two sheets of tinfoil and placing a sheet of paper between them as shown in Fig. 11A. The tinfoil and the paper are then rolled as shown in Fig. 11B until they are shaped like Fig. 11C. Wire leads are then attached to the foil sheets that protrude from each end of the capacitor.

After the leads have been attached to the capacitor it is then encased in a suitable container. In older radio and TV receivers you will find capacitors of this type that have been encased in a cardboard case with wax or some other sealing compound poured into both ends. However, this type of capacitor frequently caused trouble and is seldom used in modern electronic equipment. Modern paper capacitors are completely encased in a molded ceramic type of material or are encased in a mylar type of material. Either type completely seals the capacitor so that moisture cannot seep into it. Capacitors of this type are referred to as molded capacitors, molded paper capacitors, mylar capacitors or mylar paper capacitors.

A photo of two typical paper ca-

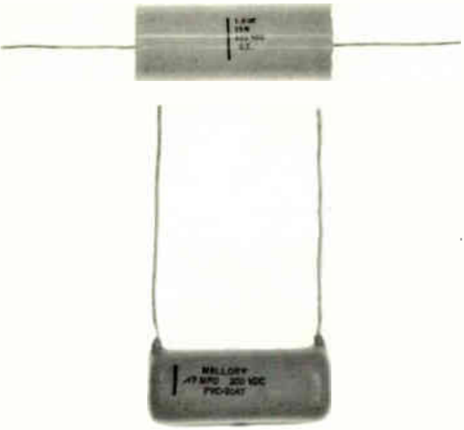


Fig. 12. Typical paper capacitors.

pacitors is shown in Fig. 12. Notice that in one capacitor the leads come out the ends. This type of lead arrangement is referred to as axial leads. In the other type of capacitor the leads come out the side and this is referred to as a radial-lead type. Capacitors with radial leads are frequently used in electronic equipment in which printed circuitry is used. This type of capacitor is very convenient for mounting in this type of construction. However, axial lead capacitors can also be used in the same application simply by bending the leads at right angles to the body of the capacitor.

Paper capacitors are made in a wide range of capacities. You will find paper capacitors as small as .0005 mfd and as large as 1 mfd or 2 mfd. Paper capacitors can be made in a larger size, but it is usually more economical to make other types when the capacity needed in a circuit exceeds about .5 mfd.

Defects.

Since you are training as an electronics technician, one of your chief concerns with capacitors will be the defects that occur in them. There are a number of different types of defects that can occur in paper capacitors. As we mentioned earlier, in older receivers you will find paper capacitors encased in a cardboard case. Moisture can seep into this type of capacitor, resulting in leakage from one plate to the other or an eventual breakdown in the paper insulation, so that for all practical purposes one plate is touching the other. Of course, when this happens the capacitor can no longer store a charge and acts as though there were a wire connected between the two leads of the capacitor.

Occasionally in a molded or a mylar type of capacitor the material encasing the capacitor will crack, particularly around the point where the leads are brought out. When this happens moisture can seep into this type of capacitor and you get exactly the same effect as moisture in the cardboard-encased capacitor.

It is usually not too difficult to identify a completely shorted capacitor, but one that has a high leakage may cause almost as much trouble as a shorted capacitor and it is much more difficult to find. There is no such thing as a perfect capacitor. There is some leakage between the plates of all capacitors. However, a good paper capacitor will usually have a leakage resistance of several thousand megohms. When the leakage resistance drops below this figure it is a sign that the capacitor is deteriorating. In some circuits a leakage resistance as low as 2 or 3 megohms can be tolerated and the circuit may work perfectly, but in other circuits a capacitor with a leakage resistance as high as 10 or 20 megohms may be totally unusable. It is too early for you to try to distinguish between these cases; the important thing for you to remember at this time is that leakage between the plates and direct shorts between the plates of capacitors are two defects that paper capacitors can develop.

Another defect found in paper capacitors is an open. The open is usually where one of the leads breaks loose from the tinfoil. Sometimes the lead will pull right out of the capacitor, and of course this is easy to spot because you can see it. But in most cases the break will be inside the capacitor so you cannot see it and you will have to rely on the way the circuit performs to give you a clue that this is a possible cause of trouble.

Another defect found in paper capacitors is an intermittent defect. Part of the time the capacitor will operate normally, but other times it may short or it may open. Again, we do not expect you to be able to find these defects at this time; the important thing is to remember that these types of defects can and do occur.

MICA CAPACITORS

Mica capacitors are somewhat larger physically than paper capacitors of equal capacity. However, mica is used in some capacitors that are to be used in high-frequency circuits. Mica capacitors are also used in the rf signal circuits of transmitters. Mica capacitors are made with capacities ranging from a few picofarads to approximately 10,000 pf. Some mica capacitors found in transmitters are designed for operation in circuits where the voltages are extremely high; capacitors with working voltages of 5000 volts are quite common.

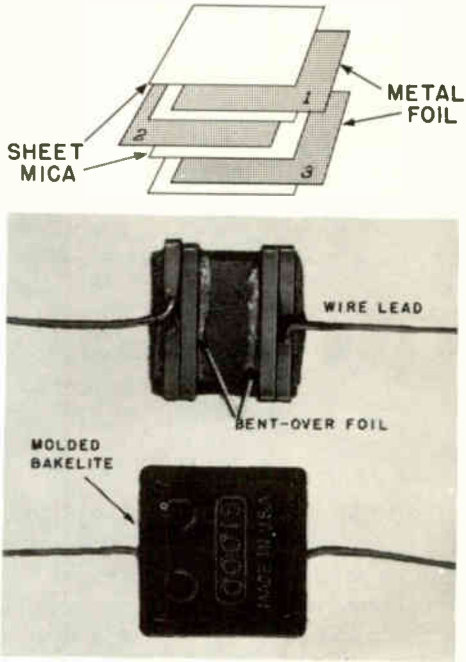


Fig. 13. How a mica capacitor is made.

The construction of a mica capacitor is shown in Fig. 13. Notice that there are simply two sets of plates, and that the plates are separated by thin sheets of mica placed between the metal plates. Because mica is brittle, this type of capacitor cannot be rolled into a tube like a paper capacitor and therefore most mica capacitors are rectangular in shape. The plates and the mica are enclosed in a ceramic or Bakelite case that is molded over the unit.

Mica capacitors seldom cause trouble. About the only defect that they ever develop is a short. Occasionally one of the leads will pull loose and the capacitor will open, but it is very rare to find any defect at all in a mica capacitor.

In spite of the fact that mica capacitors are almost trouble-free, they are not used too often in radio or TV receivers because they are more expensive than ceramic capacitors. However, in some critical circuits you will still find mica capacitors. You may find them used in the tuners of TV receivers or in critical sections of color TV receivers. They are still used almost exclusively in transmitting equipment.

As with paper capacitors, mica capacitors are available with both types of leads. Leads coming out of the end which are called axial leads are probably more common, but mica capacitors that have been dipped in mylar or some similar sealing compound are available with radial leads coming out of the side of the capacitor.

CERAMIC CAPACITORS

There are three types of ceramic capacitor found in electronic equipment. One type is the tubular, another is the disc. The third type is the feed-through. All three types are shown in Fig. 14.

Tubular ceramic capacitors are made in sizes ranging from less than 1 pf to about 1500 pf. They can be made to rather close tolerances and at one time were quite widely used in electronic equipment where small electrical size capacitors were needed. Most modern equipment, however, uses disc capacitors, because they are more economical than tubular capacitors and can also be made to quite close tolerances.

The feed-through capacitor is a special type of ceramic capacitor used exclusively as a bypass element, particularly at very high and ultra high frequencies. The unique construction of the feed-through capacitor, shown physically and schematically in Fig. 14, makes it a particularly effective bypass capacitor for filament, bias, agc and B+ leads in UHF and VHF TV tuners. One lead of the tubular feed-through capacitor connects directly to ground, whereas the fed through lead forms the other lead of the capacitor. The capacitor leads, therefore, are very short, making the capacitor extremely effective at UHF and VHF.

Disc capacitors are made with capacities from about 1 pf up to almost 1 mfd. These capacitors are made with different tolerances. Common tolerances are ±5%, or ±10% or ±20%.

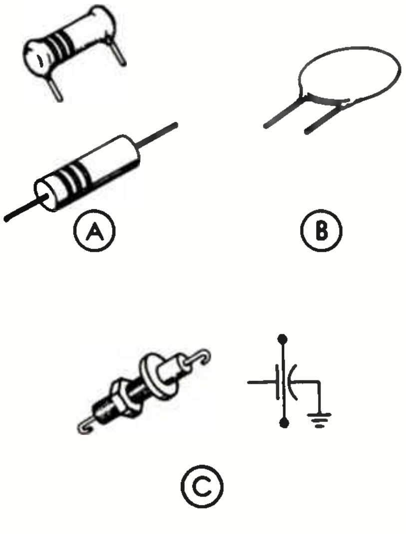


Fig. 14. Three types of ceramic capacitor. (A) Tubular; (B) Disc; (C) Feed-Through.

Sometimes the tolerance is indicated by a letter rather than by the actual tolerance figure. The letter J is used to represent a 5% tolerance, K a 10% tolerance and M a 20% tolerance. Ceramic capacitors are also made with a tolerance of +100% or -0. The letter P is used to represent this tolerance, and with a tolerance of +80%, -20% the letter Z is used.

Many types of ceramic capacitors change capacity with changes in temperature. For example, a capacitor that is labelled Z5U is a ceramic capacitor designed for operation between 10° and 85° C. The Z5 gives you this information. The letter U indicates that the capacity may change as much as +22% or -56% over that temperature range. In many circuits where ceramic capacitors are used a change in capacity is not particularly important and therefore you will find many capacitors used as bypass capacitors with the label Z5U.

Ceramic capacitors are made with lower temperature coefficients. For example, a capacitor labelled Z5F has a temperature coefficient of only ±7.5%. Z5P indicates a temperature change of 10% within the operating range.

When you have to replace a ceramic capacitor you can use one with the same temperature coefficient or one with a better temperature coefficient. The letter A indicates the smallest temperature coefficient, a change of ± 1%; the letter V is the poorest temperature coefficient. When you have to replace a ceramic capacitor, use one having the same temperature coefficient or a coefficient indicated by a letter closer to the letter A - this will be a better or closer tolerance temperature coefficient.

Ceramic capacitors normally have a voltage rating of at least 500 volts. Many have a voltage rating of 1000 volts. However, some will have a voltage rating as low as 100 volts where size is an important consideration. High-voltage ceramic capacitors having a voltage rating of 6000 volts or more are also available. Usually if the voltage rating is higher than 1000 volts or less than 500 volts, the voltage rating will be stamped on the capacitor.

Defects.

Occasionally a lead will break off a ceramic capacitor, but other than this they seldom open. Ceramic capacitors do short sometimes, but a shorted capacitor is usually not too difficult to locate. A low resistance reading across any capacitor indicates either that there is something directly across the capacitor causing the reading or else the capacitor itself is defective.

ELECTROLYTICS

There are two types of electrolytic capacitors, dry and wet. In the wet electrolytic capacitor a liquid called an electrolyte is used whereas in the dry electrolytic capacitor the electrolyte is in a paste form instead of a liquid. Wet electrolytic capacitors are no longer used. Modern electrolytic capacitors are all of the dry type.

A dry electrolytic capacitor is made of two plates with an electrolyte in paste form placed between the two plates as shown in Fig. 15. The anode plate is treated chemically before the capacitor is as-

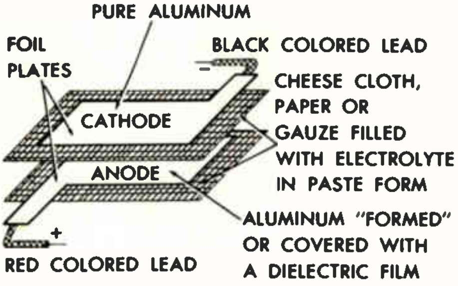


Fig. 15. How dry electrolytics are made.

sembled to produce a coating of oxide on the surface of the plate. The oxide then acts as the dielectric and the paste electrolyte acts as the other plate of the capacitor. The plate marked the cathode is the means of making contact to the paste.

Most electrolytics that you will encounter in commercial electronic equipment are made with aluminum plates. These capacitors are referred to as aluminum electrolytic capacitors. However, in some special applications, particularly where small size is important, the capacitor may be made with tantalum plates. This type of capacitor, however, is seldom found in radio or television receivers, because the tantalum plate electrolytic capacitor is much more expensive than an aluminum plate capacitor.

Polarity.

Electrolytic capacitors have polarity. This means that they can be used only in circuits having dc or pulsating dc. The plate called the anode must always be connected to the positive side of the voltage source and the plate called the cathode must always be connected to the negative side of the voltage source. If an electrolytic (technicians frequently shorten electrolytic capacitor to "electrolytic") is connected into the circuit backwards it will act as a low resistance, and a high current will flow through the capacitor, destroying it.

Dry electrolytic capacitors may be rolled into a tubular form and look very much like large paper capacitors. Flexible leads are brought out of the ends of the capacitor and the polarity of the leads is shown either by marking one end with a + sign and the other end with a - sign, or by using a wire of one color as one lead and a wire of another color as the other lead. The polarity is thus identified by the color of the lead. Usually a black wire is used to identify the negative lead and a red wire is used to identify the positive lead.

In some capacitors of this type there may actually be two electrolytic capacitors in the one container. The capacitor might be made with a common negative lead; in other words one negative lead for the two capacitors and separate positive leads so that there are only three leads coming from the capacitor or it can be made with separate positive and separate negative leads so that there are four leads brought out of the capacitor. The type with three leads, where a common negative lead is used, is found far more frequently than the type with the four separate leads.

Dry electrolytics are also sometimes placed inside a metal can. The can is the negative terminal of the capacitor and the positive terminal is brought up through an insulated wafer at the bottom of the capacitor. Sometimes there may be several separate capacitors in the one can. The can will be the common negative terminal and the separate positive leads will be brought out the bottom wafer. Symbols such as a small triangle, a half-moon or a square are cut into the wafer near the terminals to identify the various sections of the capacitor. An example of a can type electrolytic capacitor with four separate capacitors in the one container is shown in Fig. 16A. Fig. 16B shows a bottom view of the capacitor; you can see the symbols near the terminal lugs. The symbols identify the various terminals of the capacitor; the code used to identify the symbols is stamped into the metal capacitor can.

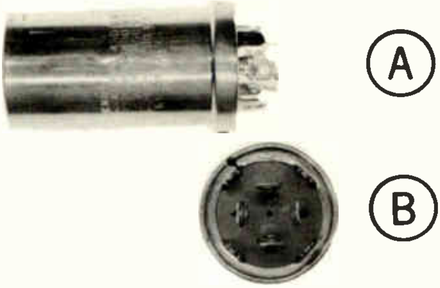


Fig. 16. A typical four-section electrolytic capacitor.

Defects.

As we mentioned previously, most electrolytic capacitors manufactured today are dry electrolytic capacitors. These capacitors deteriorate, particularly if they are not put into use. An electrolytic capacitor that has been unused for six months or more should be formed before the capacitor is put into service. An electrolytic can be formed by placing a low voltage on the capacitor and gradually increasing the voltage until it is equal to or slightly exceeds the rated working voltage of the capacitor. If a 450-volt capacitor that has been sitting around unused for six or seven months is simply installed in a circuit, and has a full 450 volts applied to it without first being formed, the chances are that it will short and the capacitor will be destroyed.

Electrolytic capacitors also deteriorate with use. The moisture in the electrolytic will slowly escape from the capacitor and when all the moisture has escaped the capacitor will really be dry and it will no longer work. Electrolytic capacitors also develop leakage. Leakage in an electrolytic capacitor can be detected quite easily; you will notice that the capacitor starts to get hot. In normal operation there is some leakage through an electrolytic capacitor and this will cause the capacitor to get warm, but if you notice that an electrolytic is getting extremely hot, it is a sign that the leakage through the capacitor is too high, and the capacitor should be replaced.

SUMMARY

In this section of the lesson you learned that there are a number of different types of capacitors. There are two types of variable capacitors, those with an air dielectric and those with a mica dielectric such as compression-type trimmers. You also learned that there are paper, mica, ceramic, and electrolytic capacitors. You are likely to run into all types, but you will probably have more to do with electrolytics than the other types because electrolytic capacitors cause more trouble than the others.

It is not important that you remember how the various types of capacitors are made; the important thing to remember is that capacitors can open, they can short, or they can develop intermittent defects. A low resistance reading across a capacitor indicates that the capacitor is shorted or has developed excessive leakage. Exactly how low a resistance can be tolerated through the capacitor depends upon the type of capacitor and the circuit in which it is used.

SELF-TEST QUESTIONS

(p) What two types of dielectrics are found in variable capacitors such as trimmer capacitors?

(q) What is the disadvantage of using a variable capacitor with straight-line capacity plates as a tuning capacitor in a radio receiver?

(r) Which type of capacitor plate is best suited for use in a tuning capacitor in a radio receiver?

(s) What is the main difference between a variable capacitor such as might be found in a radio receiver and a variable capacitor that might be found in a broadcast transmitter?

(t) What is the name given to the leads that come off the ends of a paper capacitor?

(u) Why are paper capacitors molded in a ceramic type of material or dipped in a mylar type of material?

(v) If the resistance of a paper capacitor is 100,000 ohms, would you replace the capacitor or is it satisfactory for continued use?

(w) Why are mica capacitors not more widely used in radio and television receiving equipment?

(x) In what type of circuits would you expect to find mica capacitors used?

(y) What two types of ceramic capacitors are used in electronic equipment?

(z) What does Z5F stamped on a ceramic disc capacitor indicate?

(aa) What are the two types of electrolytic capacitors, and which type is used in modern electronic equipment?

(ab) What do we mean when we say that an electrolytic capacitor has polarity?

(ac) If you notice that an electrolytic capacitor in a TV receiver is getting very hot, what should you do?

(ad) If you have a replacement electrolytic on hand that you have had for about a year, what should you do with it before installing it in a piece of equipment?

Capacitors in AC Circuits

Capacitors actually have very little use in circuits where there is nothing other than pure dc. Once a capacitor is placed in a dc circuit and charged, there will be no further current flow in the circuit. The chief importance of a capacitor comes from the way in which it works in ac circuits, and in circuits where there are ac and dc mixed together. Capacitors are used in all types of ac circuits found in electronic equipment ranging from the low frequencies found in power supplies and audio equipment up to the very high frequencies found in microwave equipment. Microwave equipment is that used at frequencies of 3000 mc (megacycles) and higher. The importance of the capacitor in ac circuits depends upon its ability to store an electrical charge. Because a capacitor can store a charge, it can be used in an ac circuit.

HOW AC FLOWS IN CIRCUITS USING CAPACITORS

In Fig. 17 a simple circuit is shown in which a capacitor is connected across an ac generator. In this type of circuit there will be a current flow. The exact amount of current flowing will depend upon the voltage of the generator, its frequency, and the capacity of the capacitor.

When the terminal of the generator marked 1 is negative and the terminal marked 2 is positive, electrons will flow from terminal 1 into the side of the capacitor marked A and force electrons out of the side marked B to terminal 2 of the generator which will attract these electrons because it is positive. During the next half cycle when the polarity of the generator reverses, electrons that have been piled up on the side of the capacitor marked A will be pulled out by terminal 1 which is positive, and electrons will be forced into side B of the capacitor by terminal 2 of the generator, which is negative. Extra electrons will be forced on this side of the capacitor so the side marked B will become negative and side marked A will become positive.

This action continues as the generator goes through first one half cycle and then the other. Electrons will flow back and forth in the circuit. They will flow first into one side of the capacitor and force electrons out of the other side and then electrons will flow out of the side on which they built up a surplus and into the side on which there was a shortage. It is important that you notice that electrons do not flow through the capacitor. You will remember that the plates of the capacitor are separated by a dielectric and the dielectric is a non-conducting material. However, because the capacitor can store a charge, we have the effect of a current flowing in the circuit.

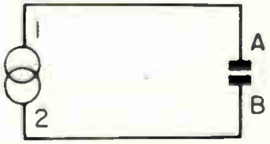


Fig. 17. A capacitor connected across a generator.

The action inside the capacitor can be seen in more detail in Fig. 18. At the start of the ac cycle when the voltage of the generator is zero, there will be a certain number of electrons on both plates of the capacitor. The electrons in each atom of the dielectric will be revolving around the nucleus as shown in Fig. 18A. However, when electrons begin to move into one plate, as shown in Fig. 18B, and out of the other plate, the electrons in the dielectric will be forced out of their normal path as shown. Thus, although the electron flowing into plate 1 does not reach plate 2, it does force another electron in the dielectric over near plate 2, and this in turn forces an electron out of plate 2.

As the ac voltage decreases and finally drops to zero, the electrons in the dielectric will return to the normal position as shown in Fig. 18C. During the next half cycle, when the polarity of the generator reverses, electrons will be forced into plate 2 and they in turn will force the electrons in the dielectric out of their normal positions and they will push electrons out of plate 1. Thus we have the effect of current flowing through the capacitor in the opposite direction, although the electrons flowing into the one plate never do get through the dielectric into the other plate of the capacitor.

You can see that there is a back and forth motion of the electrons in the conductors connected to the capacitor. The electrons in the dielectric will move back and forth and therefore we are justified in saying that ac current flows "through" a capacitor, even though the electrons never get through the dielectric into the other plate. Because of this effect, capacitors can be used in ac circuits. They are very useful in circuits where we have both ac and dc. The capacitor can be used to block dc, while at the same time allowing ac to flow through the capacitor.

The action of a capacitor in allowing electrons to flow back and forth is a good demonstration of what ac is. The actual movement of each electron is very small; however, there may be a large number of electrons moving back and forth over a very short distance. The distance of the electron's travel is unimpor-

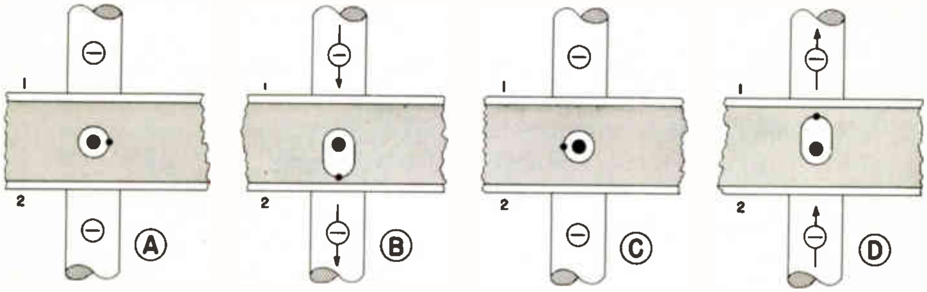


Fig. 18. When ac is applied to a capacitor, the bound electrons in the dielectric move first one way, then the other, so in effect, alternating current flows through the capacitor.

tant; the important thing is the number of electrons in motion. If we have a large number of electrons in motion, we have a large current.

The capacitor does not allow electrons to move back and forth without offering opposition. Capacitors do offer opposition to the flow of ac current through them and this opposition is called capacitive reactance.

CAPACITIVE REACTANCE

Since work must be done to move the electrons in the dielectric back and forth to permit ac current to flow, in a capacitive circuit there is opposition to the flow of current. This opposition is called capacitive reactance. This opposition is measured in ohms, just as the inductive reactance of a coil is measured in ohms. However, there is a great deal of difference between inductive reactance and capacitive reactance.

Capacitive reactance is represented by the symbol Xc. It can be expressed by the formula:

$$Xc = \frac{1}{6.28 \times f \times C}$$

In this formula the frequency f is the frequency expressed in cycles and C is the capacity in farads. We can write this formula in another way by expressing C in microfarads. To do this, we divide 6.28 into 1 and multiply this result by 1,000,000. We get:

$$Xc = \frac{159{,}000}{f \times C}$$

In this expression f is the frequency in cycles per second, and C is the capacity in microfarads.

From this formula there are several important things that you can see. First of all, let us consider the effect of a change in frequency on the reactance of a capacitor. Let us find the reactance of a 1-mfd capacitor at a frequency of 10 cycles per second. Using the formula:

$$Xc = \frac{159{,}000}{f \times C}$$

and substituting 10 for f and 1 for C we get:

$$Xc = \frac{159{,}000}{10 \times 1} = 15{,}900 \text{ ohms}$$

When the frequency is 100 cycles, we get:

$$Xc = \frac{159{,}000}{100 \times 1} = 1{,}590 \text{ ohms}$$

Notice that at the higher frequency, the capacitive reactance is lower.

As the frequency increases, the capacitive reactance decreases. In an inductive circuit we had just the opposite effect; if the frequency increased, the inductive reactance increased.

We have the same situation when the capacity is increased. If the capacity is made larger, the capacitive reactance decreases. We can see this if we find the reactance of a 1-mfd capacitor at a frequency of 100 cycles per second and then find the reactance of a 10-mfd capacitor at 100 cycles per second. We already know that the 1-mfd capacitor has a reactance of 1590 ohms. To find the reactance of the 10-mfd capacitor we use:

$$Xc = \frac{159{,}000}{100 \times 10} = 159 \text{ ohms}$$

Notice that this is one tenth the reactance of the 1-mfd capacitor at 100 cycles per second. Therefore in a capacitive circuit, we have exactly the opposite effect to what we had in an inductive circuit. We can say that the capacitive reactance varies inversely with the frequency and the capacity. This simply means that if the frequency or capacity increases, the reactance decreases, and if the frequency or capacity decreases, the capacitive reactance increases.

While we are discussing capacitive reactance it might be well to point out that the reactance of even a small capacitor becomes quite small if the frequency is made high enough. For example, a 100-pf capacitor has a reactance of 1590 ohms at a frequency of 1 megacycle. One megacycle is not a high radio frequency; as a matter of fact this frequency falls in about the middle of the standard radio broadcast band. At a frequency of 10 megacycles, which is in the short-wave bands, the reactance is only 159 ohms, and at a frequency of 100 megacycles, which is in the FM broadcast band, the reactance is only 15.9 ohms. Even a 1-mmf capacitor has a reactance of only 1590 ohms at a frequency of 100 megacycles. Thus, if the frequency is made high enough even small capacitors have a comparatively low reactance.

Capacitors in Parallel.

When two capacitors are connected in parallel we have two capacitive reactances in parallel. If the capacitive reactance of each capacitor is 100 ohms, we have the same effect as we would have with two 100-ohm resistors in parallel. The reactance would be only 50 ohms. This effect is the same as connecting a capacitor twice as large as either capacitor into the circuit.

To find the total capacity of capacitors connected in parallel you simply add the capacities. In other words, if a 4-mfd capacitor is connected in parallel with a 6-mfd capacitor, the total capacity in the circuit is 10 mfd. The reactance in the circuit would be exactly the same as you would obtain by connecting a 10-mfd capacitor in the circuit.

This is an important rule to remember--to find the total capacity of parallel-connected capacitors you simply add the capacitors together. The working voltage that can be applied to the parallel combination is the lowest working voltage of the capacitors connected in parallel.

Capacitors in Series.

When capacitors are connected in series, we have two reactances in series. The total capacitive reactance in the circuit is equal to the sum of the two reactances, just as the total resistance in a circuit made up of resistors connected in series is equal to the total resistance in the circuit. Thus connecting capacitors in series increases the total reactance in the circuit. If the reactance in the circuit increases, then the capacity must decrease.

When two capacitors are connected in series, you can find the total capacity by using the formula:

$$C_T = \frac{C1 \times C2}{C1 + C2}$$

When three or more are in series, use the formula:

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots}$$

When capacitors are connected in series, the total capacity is always less than the capacity of the smallest capacitor.

You will seldom actually have to calculate the value of series and parallel-connected capacitors. However, it is important for you to realize that connecting capacitors in series results in a lower total capacity, while connecting them in parallel results in a higher total capacity in the circuit.

SUMMARY

There are several important things that you should remember from this section of the lesson. First, remember that although current does not actually flow through a capacitor, the effect produced in the circuit is the same as though current does flow through the capacitor. Thus we say that an ac current flows through a capacitor.

Remember that we call the opposition offered to current flow in an ac circuit by a capacitor the capacitive reactance, and the capacitive reactance is measured in ohms. The capacitive reactance is equal to:

$$Xc = \frac{159{,}000}{f \times C}$$

where f is in cycles per second and C is in microfarads.

Increasing the capacity or the frequency in the circuit will result in a lower capacitive reactance and decreasing the frequency or capacity will result in a higher capacitive reactance.

When capacitors are connected in parallel, the total capacity is equal to the sum of the capacities. When capacitors are connected in series, the total capacity is always less than the capacity of the smallest capacitor.

SELF-TEST QUESTIONS

(ae) When a capacitor is connected across an ac generator, does current flow from the generator?

(af) When a capacitor is connected across a generator, does current flow through the capacitor?

(ag) What is the name given to the opposition that a capacitor offers to the flow of ac?

(ah) What is the formula used to determine the capacitive reactance of a capacitor?

(ai) What is the capacitive reactance of a .02 mfd capacitor at a frequency of 150 cycles per second?

(aj) What is the total capacitance of a .1 mfd and a .22 mfd capacitor connected in parallel?

(ak) A 27 pf capacitor and a 56 pf capacitor are connected in series. What is the total capacity of the series-connected capacitors?

(al) In what unit is capacitive reactance measured?

(am) Complete the following statement: Increasing the capacity or the frequency in a circuit will result in a ________ capacitive reactance and a decrease in frequency or capacity will result in a ________ capacitive reactance.

Simple RC Circuits

An RC circuit is a circuit containing resistance and capacity. These circuits are found in all types of electronic equipment. RC circuits are used to shape signals. We can apply a signal with one type of wave shape to an RC circuit and get a signal having a different wave shape at the output. RC circuits are used to feed signals from one stage to another in electronic equipment. There are many applications of RC circuits, but before you can understand how these circuits are used, you must learn something about the fundamentals of the circuit.

You already know that when a capacitor is connected across a voltage source it does not charge instantly, but takes a certain length of time to charge. The length of time depends upon the size of the capacitor and the resistance in the circuit. The length of time it takes to charge up to a certain value is called the time constant. Time constant is an important consideration in circuits using resistance and capacitance. Let's learn a little more about it.

TIME-CONSTANT

When a resistor is connected in series with a capacitor and the two are connected across a battery as shown in Fig. 19, current begins to flow in the circuit to charge the capacitor. At the first instant that the resistor and capacitor are connected across the battery, a rather large current flows because there is no charge on the capacitor. The size of the resistor will limit the amount of current that can flow for any given voltage source. At this instant, although the current flowing in the circuit is high, the voltage across the capacitor is zero. In other words, when the current flowing into the capacitor is at a maximum, there is no voltage across it.

Gradually the capacitor is charged and as the capacitor charges, the voltage across the capacitor builds up and the current flowing in the circuit decreases. This is due to the fact that the actual voltage driving electrons in the circuit is equal to the source voltage minus the voltage across the capacitor. As the voltage across the capacitor increases, the voltage forcing electrons through the circuit goes down. In other words the current flowing into the capacitor decreases as its voltage increases.

If we draw a graph showing the way in which a capacitor charges, it would look like Fig. 20. In this graph, time is measured along the horizontal axis. The extreme left of this axis represents the instant we connect the capacitor and resistor across the source. Notice that at this instant there is no voltage across the capacitor, but the voltage starts

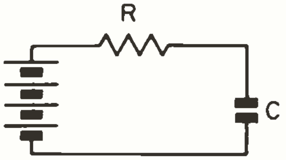


Fig. 19. A resistor and a capacitor connected in series across a battery.

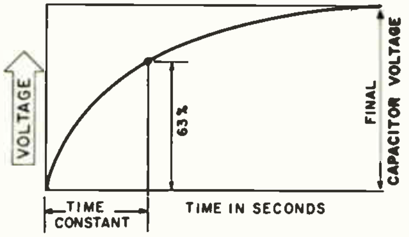


Fig. 20. How a capacitor charges. The time-constant is the time it takes for the capacitor to charge to 63% of the total voltage.

to build up rapidly. Then, as the charge on the capacitor increases, the rate of charge decreases so that when the capacitor is almost charged to a value equal to the source voltage, the rate of charge becomes very slow.

When we speak of the time-constant of an RC circuit, we mean the time it takes the capacitor to charge up to about 63% of the total source voltage. This value is shown on Fig. 20. The time-constant of any RC circuit in seconds can be found by multiplying the resistance of the resistor in megohms times the capacity of the capacitor in mfd. Thus, if a 2-mfd capacitor is connected in series with a 1-megohm resistor, the time-constant will be 2 × 1 = 2 seconds. This means that it will take two seconds for the capacitor to charge up to 63% of the source voltage.

One important thing to note is that the source voltage has nothing to do with the time-constant of the circuit. In other words, whether a resistor-capacitor combination is connected across a 10-volt battery or a 100-volt battery, the time-constant is the same. If a certain resistor and capacitor are connected across a 10-volt battery and the time-constant is one second, the capacitor will charge up to 63% of 10 volts, or 6.3 volts in one second. On the other hand, if the same resistor-capacitor combination is connected across a 100-volt battery, the capacitor will charge up to 63% of 100 volts, or 63 volts, in one second. The voltage across which the resistor-capacitor combination is connected does not determine the time-constant; the only factors that affect the time-constant are the resistor and capacitor values.

If a .05-mfd capacitor is connected in series with a 100,000-ohm resistor, the time-constant will be .05 × .1 (100,000 ohms = .1 meg) = .005 second. Thus, you can see that the time-constant of the combination using a smaller capacitor and resistor is much shorter than the time-constant of the combination of the two-mfd capacitor and the one-megohm resistor. Decreasing the size of either the resistor or the capacitor decreases the time-constant of the circuit, and increasing the size of either the resistor or the capacitor increases the time-constant of the circuit.

VOLTAGE-CURRENT PHASE

In the preceding example, you will notice that when the capacitor and resistor combination is first connected across the battery, a very high current flows in the circuit. However, at this first instant when they are connected across the bat-

$T_c = RC$

R= MEG C = MFD

tery, there's no voltage across the capacitor. Here we have a situation where the current is at a maximum, and the voltage across the capacitor is at a minimum or zero voltage.

As the voltage across the capacitor builds up, the current flowing in the circuit decreases until finally, when the capacitor is fully charged to a value equal to the battery voltage, the current drops to zero, because the source voltage is unable to force any additional electrons onto the one plate of the capacitor or pull electrons off the other plate.

Essentially the same situation exists when a capacitor is used in an ac circuit. When the ac voltage across the capacitor builds up, the current decreases until, by the time the capacitor is fully charged, the current has dropped to zero. When the voltage across the capacitor begins to decrease, then current must flow in the opposite direction in order for the electrons to remove the excess electrons from the plate of the capacitor having a surplus of electrons and to replace the missing electrons on the plate of the capacitor having a shortage of electrons. During the second half of an ac cycle, as the capacitor voltage drops from a maximum value to zero, the discharge current flowing in the circuit increases until, at the time the voltage reaches zero and begins to change polarity, the current flowing in the circuit is at maximum. As the voltage across the capacitor builds up in the opposite direction, the current begins to decrease until, at the instant when the capacitor is fully charged with the opposite polarity, the current flowing in the circuit has dropped to zero again.

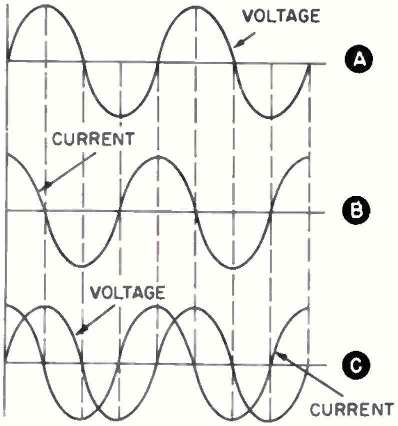


Fig. 21. The phase relationship between current and voltage in a capacitive circuit.

In Fig. 21 the relationship between the current and voltage in a capacitive ac circuit is shown. Notice that in Fig. 21A two cycles of an ac sine wave are drawn. Immediately beneath the voltage sine wave, in Fig. 21B, the current that will flow at the corresponding instant is shown. The voltage and current waves are superimposed in Fig. 21C.

In this circuit the effect is exactly opposite to that obtained when a coil is used. You will remember that in inductive circuits the current lags behind the voltage. Here, in a capacitive circuit, the current is leading the voltage. In a circuit containing only capacity, the current will lead the voltage by 90 degrees. In a circuit containing both resistance and capacity, the current will lead the voltage by a value somewhat less than 90 degrees; the actual phase difference between the voltage and current will depend upon the size of the capacitor and resistor in the circuit.

Thus, you have now seen two important examples of phase. In an inductive circuit, the current lags the voltage by 90 degrees. In a capacitive circuit, the current leads the voltage by 90 degrees.

VOLTAGE DISTRIBUTION

If we connect a capacitor in series with a resistor and connect the two across a dc voltage source, we will eventually have the situation shown in Fig. 22A. Here, all the voltage appears across the capacitor and there is no voltage across the resistor. Since there is no voltage across the resistor, we know immediately that there is no current flowing in the circuit. Of course, you know that at the instant the resistor and capacitor in series are connected across the voltage source, there will be a current flow while the capacitor is charging. However, once the capacitor is charged, there is no further current flow in the circuit and the meters would read like those shown in Fig. 22A.

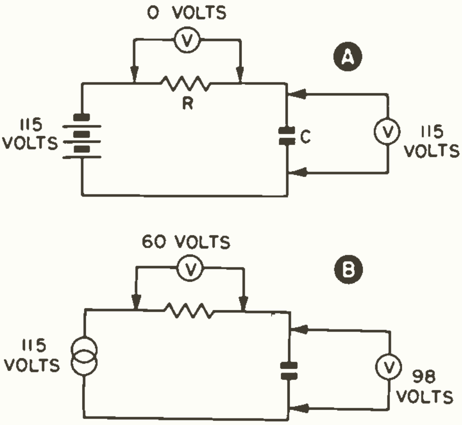


Fig. 22. When a resistor and a capacitor are connected in series across a dc source as at A, there is no current flow in the circuit. When the resistor and capacitor are connected in series across an ac generator as at B, there is current flowing, and hence there are voltage drops across R and C.

If the same resistor and capacitor are connected across a 115-volt ac source and the meters are replaced by ac voltmeters, we might encounter the situation shown in Fig. 22B. Here we have 98 volts across the capacitor and 60 volts across the resistor. 98 plus 60 adds up to 158 volts, which is more than the source voltage. It is obvious that we cannot add these two voltages in order to get the source voltage, because we know that the sum of the voltage drops in a circuit must be equal to the source voltage. The reason for the apparent contradiction is that the voltmeters indicate the RMS or effective voltage appearing across the capacitor and across the resistor. These voltages are not in phase and hence cannot be added by simple addition. You will remember that we encountered exactly the same thing when a resistor was connected in series with a coil. We found that we could not simply add the voltages appearing across the two and get the source voltage, but instead had to add the two by means of vectors. Let us see how we can do the same thing with these two voltages.

First, we start by drawing the current vector as shown in Fig. 23A. This vector is always drawn in this position since we use this as a starting point. We consider this vector as rotating in a counterclockwise direction around its starting point as the current goes through its cycle. If we use a scale of 50 volts to an

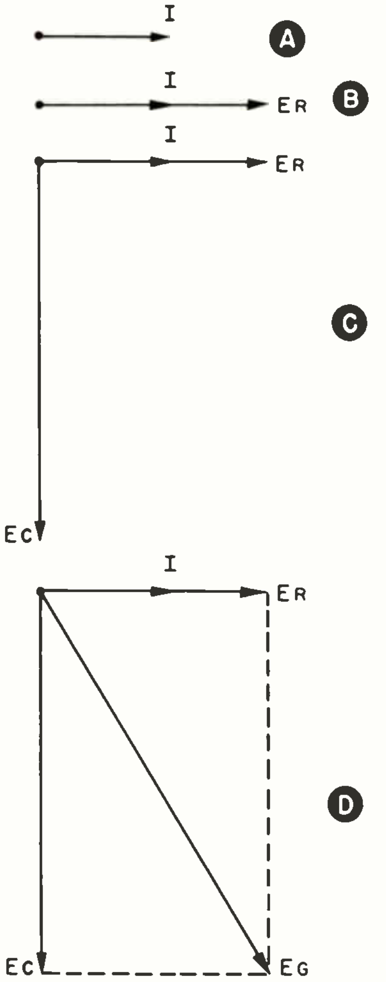


Fig. 23. Vector addition of two voltages.

inch, we can draw the vector E_R, representing the voltage across the resistor, 1-1/5 inches long as shown in Fig. 23B. We know that this vector must be drawn right on top of the current vector because the voltage across the resistor is in phase with the current flowing through it.

The next vector to draw is the vector representing the voltage appearing across the capacitor. We know that in a capacitor the current leads the voltage by 90 degrees. Another way of saying this is that the voltage lags the current by 90 degrees. Since the current vector is rotating in a counterclockwise direction, to show the voltage vector 90 degrees behind the current vector, we draw it as shown in Fig. 23C. Since the voltage across the capacitor is almost 100 volts, we can draw this vector 2 inches long as shown. Now we have only to draw in the dotted lines as shown in Fig. 23D and complete the vector diagram by drawing in the vector E_G which is the vector sum of the two voltages. If you measure this vector, you will find that it is a little more than 2-1/5 inches long, indicating a voltage of about 115 volts. In other words, when we used this scheme of adding the two voltages, we found that the voltage across the capacitor plus the voltage across the resistor, when added by means of vectors, are equal to the source voltage.

Another method of arriving at the same result is by means of the formula:

$$E_T = \sqrt{E_R^2 + E_C^2}$$

To solve this we take E_R^2, which is 60 × 60 = 3600, and add this to E_C^2 which is 98 × 98 = 9604. The sum is 13,204. $E_T = \sqrt{13{,}204}$, and the square root of 13,204 is approximately 115. Therefore the sum of the two voltages is 115 volts. As we pointed out before, if you know how to handle squares and square roots, the mathematical solution is somewhat quicker but if you do not know how to do square root, then the vector solution is entirely satisfactory.

IMPEDANCE

Because the voltage that will appear across each component in an RC circuit will depend upon the resistance or reactance of the particular part, we can draw impedance diagrams to obtain the total impedance in the circuit using the same procedure we used to add the voltage in a circuit. As an example, suppose we have a 1000-ohm resistor connected in series with a capacitor having a reactance of 1000 ohms. If we want to find the total impedance in the circuit, we proceed as follows:

First, draw the current vector as shown in Fig. 24A. Since the voltage appearing across the resistor will be in phase with the current flowing, we draw a resistance voltage vector immediately on top of the current vector. The voltage across the resistor will depend on its resistance. If we use a scale of 1000 ohms equals 1 inch, the resistance vector R is drawn, as shown in Fig. 24B, 1 inch long.

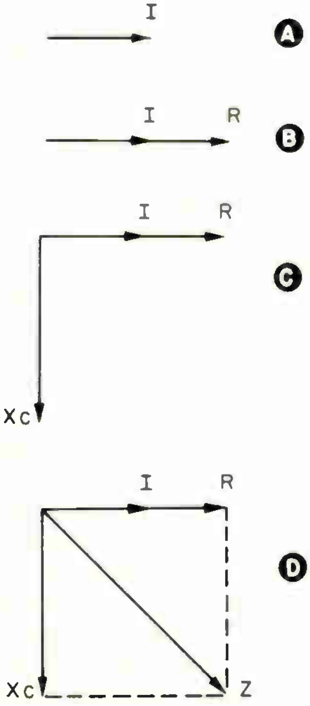


Fig. 24. Vector addition of resistance and capacitive reactance to find impedance.

Next, draw the vector shown in Fig. 24C to represent X_c. This vector also should be 1 inch long. It is drawn as shown, because the voltage appearing across the capacitive reactance will lag the current flowing in the circuit by 90 degrees.

We now complete the impedance diagram as shown in Fig. 24D, and you will find that the impedance vector Z will be 1.41 inches long. Since the scale we used was 1000 ohms per inch, the impedance of the circuit is 1410 ohms.

The same result could have been obtained mathematically by squaring the resistance and the capacitive reactance and adding the two together and taking the square root of the sum as indicated in the formula:

$$Z = \sqrt{R^2 + X_c^{\,2}}$$

It is important to notice the difference between the capacitive reactance and the inductive reactance. Notice that one is simply the opposite of the other. Notice that the impedance diagrams are drawn differently. In Fig. 25A, we see the solution of a circuit using a scale of 1000 ohms per inch where a 1000-ohm resistor is connected in series with the capacitor having a reactance of 1000 ohms. In Fig. 25B we

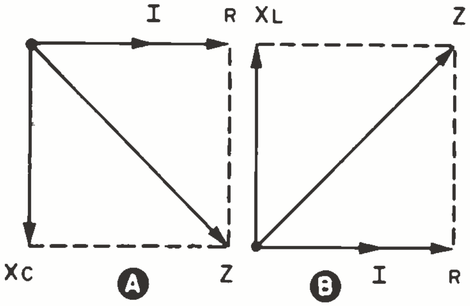


Fig. 25. When resistance and capacitive reactance are added as at A, the impedance vector lags the current; but when resistance and inductive reactance are added as at B, the impedance vector leads the current.

see an impedance diagram using the same scale, where a 1000-ohm resistor is connected in series with a coil having a reactance of 1000 ohms. Notice that we end up with the same impedance, 1410 ohms, in each case, but also notice the fact that in one case, the impedance vector leads the current vector, whereas in the other case, the impedance vector lags the current vector. In a later lesson, you will see more about these circuits and will also see the effect of having capacitive reactance and inductive reactance in the same circuit.

SUMMARY

In this section of the lesson you began the study of a very important phase of your course; you began to see what happens when resistance and capacitance are both used in the same circuit. You found that it takes a certain length of time for a capacitor to charge when the two are used in a dc circuit, and the length of time depends upon the size of the capacitor and the resistance in the circuit. The time-constant of a circuit is equal to the product of the resistance in megohms times the capacity of the capacitor in microfarads. The time-constant of the circuit is the length of time it would take to charge the capacitor to a value of 63% of the total voltage applied to the circuit.

You learned that in an ac circuit the current flowing in a capacitive circuit will lead the voltage by 90 degrees. In other words, a capacitive circuit acts exactly the opposite to an inductive circuit.

In an ac series circuit with a resistor and capacitor in series the voltage appearing across the resistance is not in phase with the voltage across the capacitor. If we have to add these voltages together, we must add them by means of vectors.

You also have learned that the impedance in an ac circuit using a resistor and a capacitor is the total opposition to current flow. The impedance can be obtained by means of the vector addition of the resistance plus the capacitive reactance in the circuit.

SELF-TEST QUESTIONS

(an) What do we mean by the time-constant of an rc circuit?

(ao) What is the time-constant of a .02 mfd capacitor charging through a 2.2 meg resistor?

(ap) If the time-constant of an rc circuit is 2 seconds when it is charged across a 10-volt battery, what will the time-constant be when it is connected across a 100-volt battery?

(aq) When a capacitor is connected across an ac generator, what is the phase relationship between the voltage and current in the circuit?

(ar) If a resistor and a capacitor are connected in series across an ac generator, what will the phase relationship between the voltage and current be?

(as) If a generator is connected across a resistor and a capacitor in series, what is the generator voltage if the voltage across the resistor is 9 volts and the voltage across the capacitor is 12 volts?

(at) What do we mean by the impedance in a series rc circuit in which a resistor is connected in series with a capacitor?

(au) If a 6-ohm resistance is connected in series with a capacitor having a capacitive reactance of 8 ohms, what will the impedance of the combination be?

LOOKING AHEAD

Up to this point in your course, you have been studying the basic action of a few important components found in electronic circuits. Other than tubes and transistors, the parts you will run into most frequently are resistors, coils, and capacitors or parts made of these three basic components. Now that you have studied each of these three parts separately, you are in a position to go ahead to see how they work together. A later lesson will discuss resonance. Resonance is perhaps one of the most important things you will study, because if it were not for resonant circuits many of the electronic miracles that we have today would not be possible.

ANSWERS TO SELF-TEST QUESTIONS

(a) When we say a capacitor is charged, we mean there is a surplus of electrons on one plate and a shortage of electrons on the other. When a capacitor is completely charged by connecting it across a voltage source, the voltage existing across the plates of the capacitor will be equal to the source voltage used to charge it.

(b) The length of time it takes to charge a capacitor is affected by the resistance in the circuit and the capacity of the capacitor.

(c) A charged capacitor does not have any more electrons on its plates than when it is discharged. Although the number of electrons on the two sets of plates is the same, some electrons have been removed from one plate and added to the other when the capacitor is charged.

(d) The capacity of the capacitor determines the amount of charge a capacitor can hold for a given applied voltage.

(e) The farad is the basic unit of capacity.

(f) The microfarad and the picofarad are the two practical units used in electronics. A microfarad is equal to one millionth of a farad, and the picofarad is equal to one millionth of a microfarad.

(g) 3300 pf. To convert microfarads to picofarads, you multiply by 1,000,000 or move the decimal point six places to the right.

(h) .00068 mfd. To convert picofarads to microfarads you divide by 1,000,000 or move the decimal point six places to the left.

(i) (1) the area of the plates (2) the spacing between the plates (3) the dielectric of the medium between the plates.

(j) The capacity will be doubled. The capacity of a capacitor is inversely proportional to the spacing between the plates. If you cut the spacing in half, the capacity will be doubled, but on the other hand if you double the spacing between the plates, the capacity will be cut in half.

(k) The dielectric constant of a material tells you how many times the capacity of the capacitor will be increased by substituting the material between the plates of the capacitor in place of air. In other words, if a material has a dielectric constant of 5, if you fill the spacing between the plates completely with that material, then the capacity will be increased five times from what it would be if the dielectric was air.

(l) The dielectric constant of air is 1.

(m) Ceramic-type materials have the highest dielectric. This is why ceramic capacitors of a given capacity will be smaller than any other type of capacitor.

(n) A material with a dielectric constant greater than air increases the capacity because it has the effect of reducing the spacing between the plates of the capacitor.

(o) The marking, 400 volts, on the capacitor means that the capacitor can be used in circuits having a dc voltage up to 400 volts. In other words, the rated maximum voltage at which the capacitor can be used is 400 volts. If you use a capacitor in a circuit where the dc voltage is 500 or 600 volts, the chances are it will break down in a short time. On the other hand a capacitor rated at 400 volts can be used in a circuit where the voltage is 300 volts or any value less than 400 volts.

(p) Air and mica.

(q) The stations on a high end of the band will be very close together and difficult to separate. On the other hand, the stations on the low end of the band will be spread out much more than they need be.

(r) A capacitor with straight-line frequency plates.

(s) The transmitter capacitor will have a much greater spacing between the plates than the receiver capacitor. The greater spacing is required to prevent arc over due to the high voltages used in the transmitter.

(t) Axial leads.

(u) To seal the capacitor so moisture can't seep into the capacitor and cause it to break.

(v) The capacitor should be replaced; a leakage resistance of 100,000 ohms is much too low for a paper capacitor.

(w) There are more economical types available which are almost as good as mica capacitors.

(x) In critical circuits where extremely stable capacitors are required.

(y) Tubular ceramic capacitors and disc type ceramic capacitors.

(z) Z5 indicates that the capacitor is designed for operation between 10° C and 85° C. The F indicates that the capacity will not change more than ±7.5% within the capacitor's normal operating range.

(aa) The two types of electrolytic capacitors are the wet and dry type. The dry type is used in modern electronic equipment; the wet type of capacitor is no longer made.

(ab) When we say a capacitor has polarity it means that it is made so that one plate must always be connected to a positive voltage and the other always to the negative voltage.

(ac) You should replace the electrolytic capacitor. The fact that it is getting very hot indicates that there is excessive current flow through it due to excessive leakage.

(ad) The capacitor should be formed. You can form it by placing a low voltage on it and gradually increasing the voltage until it is equal to or slightly exceeds the rated voltage of the capacitor. If you do not reform the capacitor and simply install it in the receiver, the chances are that it will break down.

(ae) Yes. Current flows from the generator to charge the capacitor with one polarity during one-half cycle, and then flows in the opposite direction to charge the capacitor with the opposite polarity during the next half cycle.

(af) No. Electrons flow into one plate and out of the other to charge the capacitor with one polarity during one half cycle, and then electrons flow out of the first plate and into the second to charge the capacitor with the opposite polarity during the second half cycle. Current flows back and forth in the circuit so that it has the effect of flowing through the capacitor and often we say that ac flows through a capacitor, but actually there is no electron flow across the dielectric of a capacitor unless the capacitor breaks down.

(ag) Capacitive reactance.

(ah) $X_c = \frac{1}{6.28 \times f \times C}$ where f is in cycles/second and C is in farads. Also

$$X_c = \frac{159{,}000}{f \times C}$$

where f is in cycles/second and C is in microfarads.

(ai) To find the capacitive reactance of the capacitor we use the formula:

$$Xc = \frac{159{,}000}{f \times C}$$

and substituting 150 for f and .02 for C we get:

$$Xc = \frac{159{,}000}{150 \times .02}$$

$$Xc = \frac{159{,}000}{3}$$

$$Xc = 53{,}000 \text{ ohms}$$

(aj) .32 mfd. To find the capacity of capacitors which are connected in parallel you simply add the capacities.

(ak) To find the capacity of the two capacitors connected in series we use the formula:

$$C_t = \frac{C1 \times C2}{C1 + C2}$$

and substituting 27 pf for C1 and 56 pf for C2 we get:

$$C_t = \frac{27 \times 56}{27 + 56}$$

$$C_t = \frac{1512}{83}$$

$$= 18.2 \text{ pf}$$

(al) Ohms.

(am) The complete statement should be: Increasing the capacity or the frequency in the circuit will result in a lower capacitive reactance and decreasing the frequency or capacity will result in a higher capacitive reactance.

(an) The time-constant of an rc circuit is the length of time it takes the capacitor to charge up to approximately 63% of the total source voltage.

(ao) .044 seconds. To find the time-constant you multiply the resistance in megohms by the capacity in microfarads. 2.2 × .02 = .044 seconds.

(ap) 2 seconds. The time-constant will be exactly the same because the charging voltage has no effect on the time-constant. The time-constant is determined solely by the value of the resistance and the capacitor in the circuit. In each case the capacitor will charge up to 63% of the applied voltage in 2 seconds.

(aq) The current will lead the voltage by 90°.

(ar) The current will lead the voltage by some angle less than 90°.

(as) 15 volts. You can use either a vector solution to get this answer or the mathematical solution using the formula:

$$Eg = \sqrt{E_R{}^2 + E_C{}^2}$$

$$Eg = \sqrt{9^2 + 12^2}$$

$$Eg = \sqrt{81 + 144}$$

$$Eg = \sqrt{225}$$

$$= 15 \text{ volts.}$$

(at) By impedance we mean the

total opposition to the flow of ac in the circuit. The impedance will be the vector sum of the opposition offered by the resistance plus that offered by the capacitive reactance of the capacitor.

(au) We can find the impedance using the formula:

$$Z = \sqrt{R^2 + X_C^2}$$

and substituting 6 ohms for R and 8 ohms for X_C we have:

$$Z = \sqrt{6^2 + 8^2}$$

$$Z = \sqrt{36 + 64}$$

$$Z = \sqrt{100}$$

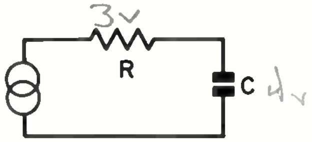
$$Z = 10 \text{ ohms.}$$

Lesson Questions

Be sure to number your Answer Sheet B107.

Place your Student Number on every Answer Sheet.

1. Name three types of solid dielectric capacitors.
2. Express .0001 mfd (microfarads) in pf (picofarads).
3. Can you use a .01-mfd, 600-volt capacitor in place of a .01-mfd, 400-volt capacitor?
4. What will happen to an electrolytic capacitor if you install it in a circuit with the wrong polarity?
5. What is the capacitive reactance of a 10-mfd capacitor at a frequency of 10 cycles?
6. What is the total capacity of a 6-mfd capacitor and an 8-mfd capacitor connected in parallel?
7. What is the total capacity of two 8-mfd capacitors connected in series?
8. What do we mean by the time-constant of an RC circuit?
9. What is the phase relationship between the voltage across a capacitor and the current flowing through the capacitor in an ac circuit?
10. If the voltage across R is 3 volts and the voltage across C is 4 volts, what is the generator voltage in the circuit shown?



THE VALUE OF COURTESY

A recent survey showed that people complain more about discourteous clerks than about any other fault a business could have. In fact, many people pay extra at higher-priced stores just to get the courtesy and respect they feel entitled to.

Regardless of whether you work for someone else or have a radio business of your own, plain ordinary courtesy can bring many extra dollars to you.

Courtesy becomes a habit if practiced long enough. Be courteous to everyone -- to members of your family, to those who don't buy from you, even to the very lowest persons who serve you -- then you can be sure you'll be courteous when it really counts.

Give your courtesy with a smile. There is an old Chinese proverb which says, "A man who doesn't smile shouldn't keep a shop." And you're keeping a "shop" even if you are selling only your ability and knowledge to an employer. A friendly smile is itself courtesy of the highest type, bringing you unexpected returns in actual money as well as friendship.

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ACHIEVEMENT THROUGH ELECTRONICS

HOW RESISTORS, COILS AND CAPACITORS ARE USED TOGETHER

B108

NATIONAL RADIO INSTITUTE • WASHINGTON, D. C.

HOW RESISTORS, COILS, AND CAPACITORS ARE USED TOGETHER

B108

STUDY SCHEDULE

By dividing your study into the steps given below, you can get the most out of this part of your NRI Course in the shortest possible time. Check off each step when you finish it.

☐ 1. **Introduction** . . . . **Pages 1 - 2**

Here you get a general idea of how resistors, coils, and capacitors are used together.

☐ 2. **Series-Resonant Circuits** . . . . **Pages 3 - 16**

You study RL and RC series circuits, and learn the effects of varying inductance, capacitance, and frequency.

☐ 3. **Parallel-Resonant Circuits** . . . . **Pages 17 - 23**

You study the effect of varying resistance, capacity, inductance, and frequency in a parallel-resonant circuit.

☐ 4. **Comparison of Series-Resonant and Parallel-Resonant Circuits** . . . . **Pages 23 - 26**

You learn how to tell whether a circuit is a parallel-resonant or a series-resonant circuit, and study the important characteristics of each.

☐ 5. **How Resonant Circuits Are Used** . . . . **Pages 27 - 31**

You learn how resonant circuits are used to select desired signals and reject undesired ones.

☐ 6. **RC Circuits** . . . . **Pages 32 - 36**

You study coupling circuits, differentiating circuits, and integrating circuits.

☐ 7. **Answers to Self-Test Questions** . . . . **Pages 37 - 40**

☐ 8. **Answer the Lesson Questions.**

☐ 9. **Start Studying the Next Lesson.**

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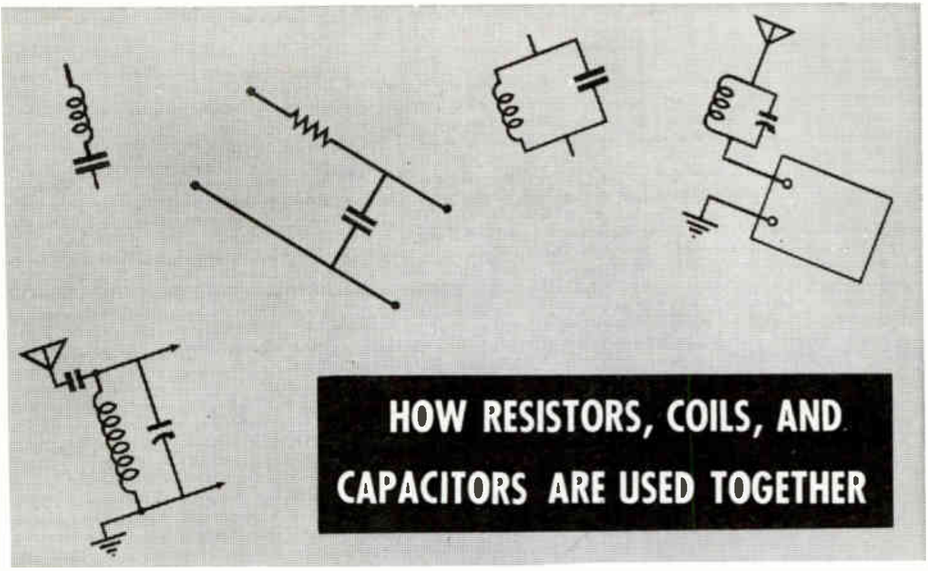


HOW RESISTORS, COILS, AND CAPACITORS ARE USED TOGETHER

In the preceding lessons you have studied resistors, coils and capacitors. Other than tubes and transistors, these are the three most important parts you will run into in electronic equipment. In your studies of these parts you have been primarily concerned with the part itself, with its characteristics and briefly with how it is made. In electronic equipment these parts are seldom used alone; in most cases two or more of these parts will be used together. For example, in coupling circuits, you will often use combinations of resistors and capacitors to feed the signal from one audio stage to a second audio stage. Circuits of this type are referred to as RC coupling circuits.

You will run into circuits where coils and resistors are used together. Circuits of this type are referred to as RL circuits. You will also encounter circuits where coils and capacitors are used together. These circuits are referred to as LC circuits. In this lesson we will study all three types of circuits but will spend most of the time on LC circuits because these are perhaps the most important of the three.

From your studies of the coil and the capacitor you might remember that in many ways one is the opposite of the other. For example, in a circuit having only inductance, you will recall that the voltage leads the current by 90°. On the other hand, in a circuit having only capacitance, the voltage lags the current by 90°. In other words, we will get the exact opposite effect; with a coil we have a 90° leading voltage and with a capacitor a 90° lagging voltage.

In circuits where coils and capacitors are used together the two more or less work against each other. In some of these circuits, the circuit may act like a coil and the voltage will lead the current by some angle less than 90°. In other circuits you may find that the circuit acts like a capacitor and the voltage lags the current by some value less than 90°. In still other circuits the effect of the coil will cancel the effect of the capacitor so that the voltage and the current will be in phase. Circuits of this type are called resonant circuits. Resonant circuits are extremely important. They are used in radio and TV receivers to separate the various stations. In other words, a resonant circuit is used in a broadcast-band receiver to select the station you want to listen to and at the same time reject the unwanted stations. Resonant circuits are used in TV receivers to tune the set to the channel you want. Without resonant circuits there would be no way to separate the stations.

There are two types of resonant circuits. One is called a series-resonant circuit, and the other is called a parallel-resonant circuit. Whether a circuit is series-resonant or parallel-resonant depends upon how the voltage is applied to the coil and the capacitor in the circuit. Both types are important; we will study both and you will soon see how to distinguish one type from the other. Since it is a little easier to see exactly what is happening in a series-resonant circuit than it is in a parallel-resonant circuit, we will study the series-resonant circuit first.

Series-Resonant Circuits

A resonant circuit is a circuit in which the inductive reactance of the coil is equal to the capacitive reactance of the capacitor. When the voltage is applied to the coil and the capacitor in series we call the circuit a series-resonant circuit. To help you get a clear understanding of what a series-resonant circuit is, let us start with a simple series circuit and review some of the things you already know.

A SERIES CIRCUIT

Let's begin with the circuit shown in Fig. 1, consisting of a 500-cycle ac generator that is generating a voltage of 120 volts. Across this generator we will connect a variable resistor, which is set so that it has a resistance of 120 ohms. If we have a voltmeter connected across the resistor, the voltage reading will be close to 120 volts. This is true because the resistor is connected directly across the generator, and the voltage being supplied by the generator is 120 volts. An ammeter connected in series with the resistor will indicate that the current flowing in the circuit is 1 ampere. Actually, we do not need the ammeter to tell us this, because we know that we can determine the current by dividing the voltage by the resistance. Remember this formula for Ohm's Law:

$$I = \frac{E}{R}$$

Therefore

$$I = \frac{120}{120} = 1 \text{ amp}$$

In this simple circuit we know that the current will be in phase with the voltage, because the only element connected in the circuit is resistance. This means that the voltage across the resistor will reach its peak at the same time that the current flowing in the circuit is at a maximum.

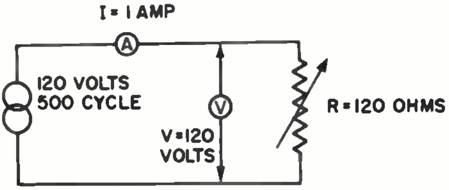


Fig. 1. A simple series circuit.

Remember that the voltmeter and the ammeter are measuring the effective value (or the rms value) of the ac voltage and current and that during part of the cycle, the generator voltage actually exceeds 120 volts. You will recall that the peak voltage of an ac sine wave will be 1.41 times the effective voltage. Therefore, even though the meter is reading 120 volts, the voltage will be greater than this value during part of the cycle and less than this value during the other part of the cycle. The voltage will actually be zero twice each cycle. Likewise, the current is the effective current and its actual value will be greater than 1 amp twice each cycle and less than 1 amp the remainder of the time. The current will reach a peak value of 1.41 amps twice each cycle and will actually drop to 0 twice each cycle.

AN RL CIRCUIT

Now let us see what happens when we modify the simple circuit of Fig. 1 by adding a 100-mh (millihenry) coil in series with the resistor as shown in Fig. 2. In Fig. 1 we showed the resistor as a variable resistor. We did this deliberately because you know that any coil will have some resistance. If the 100-millihenry coil has a resistance of 10 ohms, we can adjust the variable resistor so that its resistance is only 110 ohms. Now we will still have a total of 120 ohms resistance in the circuit: the 110 ohms from the resistor and the 10 ohms from the coil. In Fig. 2, we have represented the total resistance made up of the coil resistance and the resistance of the variable resistor as only one 120-ohm resistor. Notice that in Fig. 2 we have the ammeter in series with both the coil and resistor and have added a second voltmeter across the coil. But look at the readings on the meters! The ammeter shows that the current flowing is .35 amp. The voltmeters show that the voltage across the resistor is 43 volts, and the voltage across the coil is 112 volts. You have already seen this type of circuit, and probably know why we have obtained these readings, but let's go through this again to be sure you understand why such voltage readings are obtained. You may at first think this looks complicated, but actually it is not nearly as difficult as it might appear.

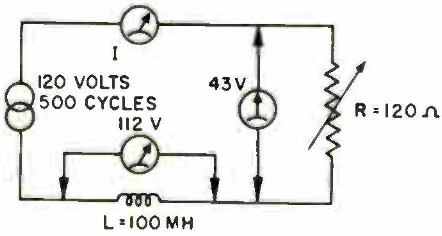


Fig. 2. A simple RL series circuit.

First, we have a series circuit. We know that the total opposition to the current flowing in the circuit will be the impedance of the circuit, which in turn is made up of the 120-ohm resistance plus the inductive reactance of the coil. We can find the inductive reactance of the coil from the formula:

$$X_L = 6.28 \times F \times L$$

Since 100-mh is .1 henry, L = .1 and F = 500 cycles, we have:

$$X_L = 6.28 \times 500 \times .1$$
$$= 314 \text{ ohms}$$

As you might expect, it is extremely difficult to make a coil with an inductance of exactly 100 millihenrys. Furthermore, we are not interested in exact calculations in most electronic circuits. To simplify things, we are going to call the inductive reactance of the coil 315 ohms. The impedance of the circuit is therefore equal to 120 ohms plus the reactance of 315 ohms. To show this by means of symbols, electronics men write this as

$$Z = 120 + j315$$

The letter j is used to indicate that 315 ohms is a reactive component which cannot be added directly to 120 ohms to get the total impedance of the circuit. If we simply wrote the impedance as 120 + 315, it would be very easy to forget that 120 was resistance and 315 was reactance and simply add the two and get 435 ohms, which of course, is incorrect.

The value of Z can be determined either by vectors as shown in Fig. 3 or from the formula

$$Z = \sqrt{R^2 + X^2}$$

In this case R is 120 ohms, and X is the inductive reactance, which is 315 ohms. So we have:

$$Z = \sqrt{120^2 + 315^2}$$

Remember that the small 2 to the right of 120 and 315 means that the number is to be squared, and that 120 squared is equal to 120 times 120. If you want to go through the arithmetic, the actual operations of squaring these numbers are as follows

$$\begin{array}{r} 120 \\ \times\ 120 \\ \hline 2400 \\ 120 \\ \hline 14400 \end{array} \qquad \begin{array}{r} 315 \\ \times\ 315 \\ \hline 1575 \\ 315 \\ 945 \\ \hline 99225 \end{array}$$

Now that we have the value of 120 and 315 squared, we have

$$Z = \sqrt{14{,}400 + 99{,}225}$$

and by adding these we will get

$$\begin{array}{r} 14400 \\ +\ 99225 \\ \hline 113625 \end{array}$$

Therefore $Z = \sqrt{113{,}625}$

To get the value of Z we have to take the square root of 113,625. This is done by first writing the number down and then marking it off in groups of two numbers working from the decimal point to the left. The steps in getting this square root are as follows:

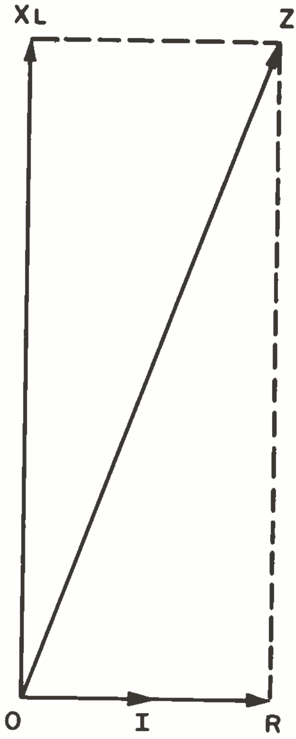


Fig. 3. Vector addition of R and X_L using a scale of 100 ohms = 1 inch, when R = 120 ohms, and X_L = 315 ohms. R is drawn 1.2 inches long, and X_L is drawn slightly less than 3.2 inches long. The impedance vector Z is then found by completing the rectangle and drawing Z from zero to the junction of the dotted lines. Z will measure between 3.25 and 3.5 inches, giving a Z of about 340 ohms.

$$\begin{array}{r|l} & \sqrt{11'\,36'\,25'} \quad \underline{|337} \\ & 9 \\ \underline{63} & \overline{2\,36} \\ & 1\,89 \\ \underline{667} & \overline{47\,25} \\ & 46\,69 \\ & \overline{56} \end{array}$$

Therefore, the impedance of the circuit is 337 ohms. We need not be concerned if there is a slight remainder when we work out the square root because electronic parts have considerable tolerance, and 337 ohms is close enough. As a matter of fact, in many practical problems you could probably round this off either to 335 or 340 ohms. However, we'll use 337 ohms.

Now that we know the total impedance in the circuit, we can determine what the current flowing in the circuit would be in this manner:

$$I = \frac{E}{Z} = \frac{120}{337} = .356 \text{ amp}$$

The ammeter we have connected in the circuit should and does read about .35 amp.

Now that we know the current flowing in the circuit, we can determine the voltage that will appear across the coil by multiplying the reactance of the coil by the current flowing in the circuit. In other words:

$$E_L = I \times X_L$$

Multiplying .356 × 315 we get 112.14 volts. We do not have to be concerned with such accuracy as this; we will simply call the voltage 112 volts. As a matter of fact this is the voltage indicated by the voltmeter connected across the coil; you cannot get a more accurate reading. Similarly, the voltage across the resistor is

$$E_R = I \times R$$

which is equal to .356 × 120, or 42.72 volts. We will round this off to 43 volts, which is what the meter will indicate.

Each of the steps that we have shown in the preceding example is important. It is not particularly necessary that you sit down and follow through the multiplication and division unless you want to do so. If you expect to go into radio and TV servicing you will have no occasion to do this type of work, but if you intend to go into industry as an electronics technician, you should be sure you understand the various steps in this circuit explanation.

Whether you go through the mathematics or not, there are several important points you should see. The current flowing in the circuit is limited by the impedance of the circuit. The impedance, as you know, is the total opposition to current flow in the circuit. The voltage that will appear across each part in the circuit will depend upon the resistance or reactance of that part and upon the current flowing in the circuit. Also, you should remember that in this example, although it may appear that the sum of the voltage across the coil plus the voltage across the resistance is greater than the source voltage, the meters are measuring the effective value of the voltage and that these voltages are not in phase. These voltages are ac voltages and hence continually changing, but the voltage across the resistor plus the voltage across the coil at any given instant is exactly equal to the source voltage at that instant.

THE RC CIRCUIT

Now, let's remove the 100-mh coil from the circuit and put a 1-mfd capacitor in its place. We will readjust the variable resistance so that the total resistance of the circuit is 120 ohms. We will then have the circuit shown in Fig. 4. Notice that

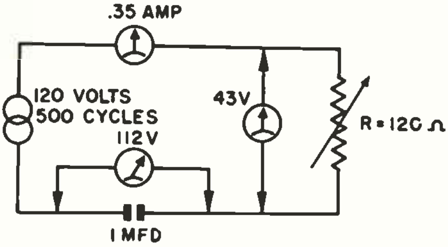


Fig. 4. A simple RC series circuit.

the voltage across the resistance is the same as in Fig. 2, and also notice that the voltage across the capacitor in Fig. 4 is the same as the voltage across the coil in Fig. 2.

We can verify all the meter readings shown in Fig. 4 as we did for the circuit shown in Fig. 2. To do this, we start by finding the reactance of the 1-mfd capacitor at 500 cycles from the formula:

$$X_C = \frac{1}{6.28 \times F \times C}$$

The capacitive reactance of the capacitor turns out to be 318 ohms. We will round this off to 315 ohms, because it is unlikely that the capacitor will have a capacity of exactly 1 microfarad. You do not have to go through the solution of this formula unless you want to, but for the benefit of those who want to work it out step by step we'll go through it.

First, remember that in the formula the frequency must be in cycles and the capacity must be in farads. Therefore, F = 500 cycles and C = 1 mfd = .000001 farad. Substituting these values in the formula we have

$$X_C = \frac{1}{6.28 \times 500 \times .000001}$$

Now we can start by multiplying 6.28 × 500 and we will get

$$\begin{array}{r} 6.28 \\ \times\ \ 500 \\ \hline 3140.00 \end{array}$$

Next, multiplying 3140 by .000001, we will get

$$\begin{array}{r} 3140 \\ \times\ .000001 \\ \hline .003140 \end{array}$$

The next step in our problem is to divide 1 by .003140. To perform the division we must get rid of the decimal point; to do this we move the decimal point six places in the divisor and six places in the dividend so that our problem becomes 1000000 divided by 3140:

$$.003140\overline{)1.000000}$$

$$\begin{array}{r} 318 \\ 3140\overline{)1000000} \\ \underline{9420} \\ 5800 \\ \underline{3140} \\ 26600 \\ \underline{25120} \\ 1480 \end{array}$$

As we mentioned we will round off the value of the capacitive reactance to 315 ohms. The difference is so small that whether it is 315 or 318 you won't be able to detect any difference in the meter readings in Fig. 4. Using 315 ohms as the capacitive reactance makes the total impedance of the circuit

$$Z = 120 - j315$$

Notice that in this case we have used -j to indicate that 315 ohms is a capacitive reactance. Actually, whether the sign is minus or plus will make no difference in determining the value of the impedance. We still use the formula:

$$Z = \sqrt{R^2 + X^2}$$

In this case, X is the capacitive reactance. Even though it is shown as -j315, it will still be + when squared, because any number squared is positive. Our formula is therefore the same as before:

$$Z = \sqrt{120^2 + 315^2}$$

The impedance works out again to be 337 ohms. The current flowing in the circuit can then be found by dividing the voltage by the impedance; this is 120 ÷ 337, or .356 amp. We can find the voltage across the resistor by multiplying the current, .356 amp, by the resistance, 120 ohms. Thus, .356 × 120 = 43 volts. Similarly, the voltage across the capacitor is .356 × 315, or 112 volts.

It is worthwhile to notice that since the circuit shown in Fig. 2 contains inductance and resistance the current will be lagging the voltage. In the circuit shown in Fig. 4 the current will be leading the voltage since we have capacitance and resistance. Nevertheless, the total impedance is the same in the two circuits; therefore, the currents flowing in the circuits are equal, which accounts for the equal voltage appearing across the resistors in each circuit.

Now let us see what happens when we go one step further and put the 100-mh coil in series with the 120-ohm resistor and the 1-mfd capacitor.

THE RESONANT CIRCUIT

In the circuit shown in Fig. 5, we have 120-ohm resistance in series with the 100-mh coil and the 1-mfd capacitor, and the series combination connected across the 120-volt, 500-cycle generator. The inductive reactance of the coil and the capacitive reactance of the capacitor will each be approximately 315 ohms as before, because the frequency in the circuit has not changed. Therefore, the total impedance in the circuit will be

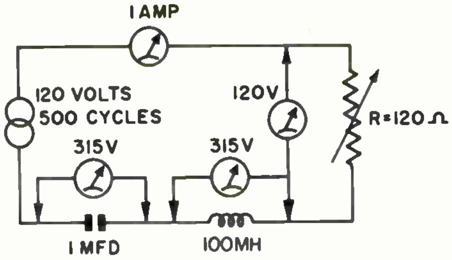


Fig. 5. A series-resonant circuit.

$$Z = 120 + j315 - j315$$

We have already pointed out that capacitive reactance is essentially the opposite of inductive reactance. We have indicated this by using +j to represent inductive reactance and -j to represent capacitive reactance.

In the expression for the impedance of the circuit you see +j315 and -j315, and, as you might expect, these two cancel so that the total impedance of the circuit is equal to the resistance of the resistor alone, or 120 ohms.

Now let's see what happens to the voltages and current throughout the circuit. First, look at the current flowing; it is 1 amp. It is higher than it was in Fig. 2 and Fig. 4. The reason for this is that the current is equal to

$$I = \frac{E}{Z}$$

Z in Fig. 5 is 120 + j315 - j315, or 120 ohms. Therefore I = 120 + 120, or 1 amp.

The voltage across the coil is 315 volts. This is equal to the current times the inductive reactance: 1 amp × 315 ohms = 315 volts. Similarly, the voltage across the capacitor will be equal to 315 volts. The voltage across the resistor is 120 volts. Notice what we now have across the capacitator and across the inductance: a voltage several times the source voltage. This is referred to as a "resonant voltage step-up." In other words, the voltage across the coil and the voltage across the capacitor in a series-resonant circuit may be several times the source voltage.

In the preceding example we saw that the impedance of the circuit at resonance is equal to the resistance in the circuit. Now you might wonder what happens when you change the resistance in the circuit. If you reduce the value of the resistance in the circuit, you will reduce the impedance. If we cut the resistance in half so that the total resistance in the circuit is only 60 ohms, the current flowing in the circuit will be doubled. We will then have the situation shown in Fig. 6. Here the voltage drop across the capacitor is equal to 2 amps × 315 ohms, or 630 volts. Similarly, the voltage appearing across the coil will be 630 volts and the voltage across the resistor will be 2 amps × 60 ohms, which is equal to 120 volts as before. Now we have an even greater resonant voltage step-up than we had previously. Reducing the resistance still further will result in an even greater voltage appearing across the coil and across the capacitor.

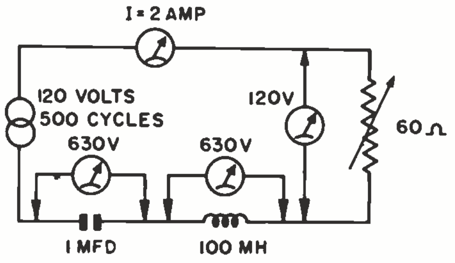


Fig. 6. Reducing the resistance in the series-resonant circuit results in a greater current flow and a higher resonant voltage step-up.

In a practical resonant circuit, we will have only a capacitor and a coil in series. However, there will always be resistance in the circuit because the coil is made by winding turns of copper wire on a coil form, and the copper wire has resistance. However, the lower that resistance can be made, the lower the impedance of the circuit and the greater the resonant voltage step-up will be.

This can be expressed in another way. The Q of a coil is equal to the inductive reactance divided by the resistance of the coil. In other words:

$$Q = \frac{X_L}{R}$$

In a coil where the resistance is low, the value of Q will be high. Since the lower the resistance we have, the greater the resonant step-up voltage will be, we say that there will be more resonant voltage step-up in a high-Q circuit than in a low-Q circuit.

Series-Resonant Facts.

Before going ahead with our study of series-resonant circuits, we should review several of the things that we have already discussed.

First, in a series-resonant circuit at resonance the inductive reactance is exactly equal to and cancels the capacitive reactance in the circuit so that the impedance of the circuit is equal to the resistance in the circuit. The impedance in the circuit will therefore be low, and the current flowing in the circuit will be high. Second, there is a resonant voltage step-up in a series-resonant circuit.

Remember these two facts -- they are important: in a series-resonant circuit you will have low impedance and high current and the voltage appearing across either the capacitor or inductance may be several times the source voltage.

Resonance occurs when the inductive reactance of the coil exactly equals the capacitive reactance of the capacitor. In other words,

$$X_L = X_C$$

$$6.28 \times F \times L = \frac{1}{6.28 \times F \times C}$$

and from this we can get:

$$F = \frac{1}{6.28 \times \sqrt{L \times C}}$$

This is the frequency at which a coil and a capacitor will be resonant.

VOLTAGE AND CURRENT WAVEFORMS IN THE SERIES-RESONANT CIRCUIT

In any series circuit, the current is always the same in all parts of the circuit. This is true whether it is a resonant circuit or a simple series circuit consisting of a number of resistors. Therefore, in a circuit such as the one shown in Fig. 7A the current flowing through the generator will be equal to the current flowing through the coil at all times, whether the circuit is resonant or not. This current is also equal to the current flowing through the resistor and to the current flowing through the capacitor.

If the circuit shown in Fig. 7A is a resonant circuit, we can make use of the fact that the current is the same at all times in all parts of the circuit to get a better idea of what is happening. We can do this by studying the voltage and current waveforms throughout the circuit. For example, we have shown two cycles and have identified a number of points on these cycles by numbers in Fig. 7B. This waveform represents the entire current flowing in the series-resonant circuit.

Look at the current waveform at point 1 and notice that the current begins swinging in a positive direction. Let's assume that at this instant the voltage at terminal a of

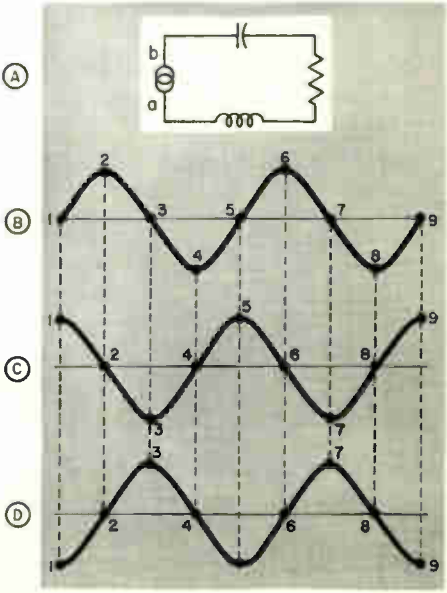


Fig. 7. Series-resonant circuit waveforms.

the generator begins to swing in a negative direction so that current starts flowing at terminal a through the coil and around the circuit back to terminal b of the generator. As the waveform increases in amplitude from point 1 to point 2, current increases in the circuit going from 0 at point 1 to its maximum value at point 2.

Although we have started the waveform shown in 7B at point 1, we are actually representing what happens in a series-resonant circuit in which the current has been flowing for some time. In other words, the circuit has been connected to the generator (which is producing the current) and we simply started to analyze what is happening in the circuit at the given instant designated at point 1 on the curve B. At this instant the current flowing in the circuit has just reached 0 and has begun to increase towards point 2 as electrons move from terminal a of the generator around the circuit towards terminal b of the generator.

Fig. 7B is a sine wave. A sine wave changes value at a maximum rate at the instant it is going through 0. In other words, at point 1 the rate at which the value of the current (represented by the sine wave) changes is at a maximum. As the actual current amplitude increases towards point 2, the rate of change decreases until for an instant at point 2 there is no change in current. The current has reached its maximum value, it remains constant for just an instant at point 2, and then begins to decrease. The rate at which it decreases increases until it is changing at its maximum rate when it reaches point 3. For just an instant the current drops to 0 at point 3. Thus, the current goes through a complete change - the instant before it reaches point 3 it is flowing in one direction, it drops to 0 exactly at point 3 and then an instant later it is flowing in the opposite direction.

Now let us consider what effect this changing current has on the voltage across the coil. Remember that the self-induced voltage in a coil depends upon the rate at which the current flowing through the coil changes. Therefore, at point 1, since the current is changing at its maximum rate, the self-induced voltage induced in the coil will be at maximum. As the current increases in amplitude towards point 2, the rate at which it is changing decreases so the voltage induced in the coil decreases. At point 2, where the current is not changing at all, the voltage induced in the coil will be 0. This is shown by the portion of curve C between points 1 and 2. Now, as the current begins to decrease from point 2 to point 3 the rate at which the current is changing increases. Since the current is decreasing, a voltage is induced in the coil which tends to oppose the direction in which the current is changing. Therefore, as the current goes from point 2 to point 3 (as shown in the curve at B), the voltage across the coil will increase from 0 at point 2 to its maximum value at point 3 (as shown in the curve at C).

Notice that the voltage across the coil is leading the current by 90°. If you remember your earlier studies, this is exactly what you might expect. As the current goes through the remainder of its cycle (as shown from point 3 on over to point 9), the voltage across the coil will at all times be 90° ahead of this current.

Now let us consider what must be happening across the resistor and capacitor in the circuit. At point 1 on curve B the actual value of the current flowing is 0. Therefore, the voltage across the resistor must be 0 because it will be in phase with the current. We have not drawn a wave shape to represent the voltage across the resistor because it will be in phase with the current waveform shown at B at all times.

Since the voltage across the generator is 0 at point 1 and the voltage across the resistor is also 0 at point 1, we immediately see that the voltage across the capacitor must be exactly equal to and opposite to the voltage across the coil. We know this must be true because in any closed circuit of this type the algebraic sum of the voltage drops around the circuit must be equal to 0. Indeed, if the circuit has been in operation the capacitor would be charged with a polarity equal to and opposite to the voltage across the coil at the instant that the current was at 0, as at point 1. As the current increases from point 1 to point 2, electrons will flow into the capacitor to reduce the charge until at point 2 the charge on the capacitor will be exactly equal to 0. As current continues to flow in the same direction (as shown from point 2 to point 3 on curve B) electrons will continue to flow into one plate of the capacitor and charge it (as shown between points 2 and 3 on curve D).

Notice what has happened. At each instant, the voltage across the capacitor is equal to and opposite to the voltage across the coil. Also notice that the voltage across the capacitor is lagging the current flowing in the circuit by 90°. This is as we should expect; when you studied capacitors in earlier lessons, you learned that the voltage lags the current in a capacitor by 90°.

The curves in Fig. 7 show what happens in a series-resonant circuit and why the voltages around the circuit (if they are measured separately, then added together) will be equal to a value greater than the source voltage. If you measure the capacitor voltage you'll be measuring the rms value of the waveform shown at D. If you measure the coil voltage you will be measuring the rms value of the curve shown at C. While these voltages do exist across the components, they are always 180° out of phase and therefore as far as the total voltage across the two is concerned they cancel each other.

In a series-resonant circuit that has a pure inductance and a pure capacitance in series with a resistor, the voltage across the inductance is exactly cancelled by the voltage across the capacitance. In this case, the applied voltage is developed across the resistor. However, pure inductors and capacitors do not exist. All coils have some resistance and all capacitors have some leakage. Therefore, the voltages across the coil and capacitor do not exactly cancel. Thus, a small voltage can be measured across the coil-capacitor combination.

Before going on to the next section of the lesson it would be worthwhile to study carefully the waveforms shown in Fig. 7 to be sure you understand what is happening. It might make it easier for you if you can redraw the circuit and place a resistor next to the generator instead of between the coil and the capacitor. Actually, insofar as the current flow in the circuit and the voltage across the individual parts in the circuit are concerned, it makes no difference where the parts are placed. However, to see how the voltages across the coil and capacitor are cancelling, it might be easier to see this if you move the resistor so that it is not between the two.

VARYING L, C, F, AND R

When the inductive reactance in a series circuit is equal to the capacitive reactance, the circuit is at resonance, the two cancel each other, and we will have a low-impedance circuit in which we will get a high current flow. Let us see what happens if we use other values of C and L and if we vary the frequency of the voltage applied to the circuit. Let's start by seeing what will happen when we vary the value of the capacitor.

Varying C.

We can vary the value of C by inserting capacitors of different sizes in the circuit in place of the 1-mfd capacitor, while leaving the source frequency at 500 cycles and the coil inductance at 100 millihenrys. The current in the circuit will vary as shown in Fig. 8. Notice that we have the highest current flowing exactly at resonance. As the capacity is reduced, the current drops off rather sharply. It is important for you to realize that as the capacity is made smaller than it should be for resonance, the capacitive reactance in the circuit increases so that it is greater than the inductive reactance. Therefore, the inductive reactance does not completely cancel out all the capacitive reactance in the circuit, and the resonant circuit begins to act like a circuit having only capacity. In other words, the current flowing in the circuit will lead the voltage.

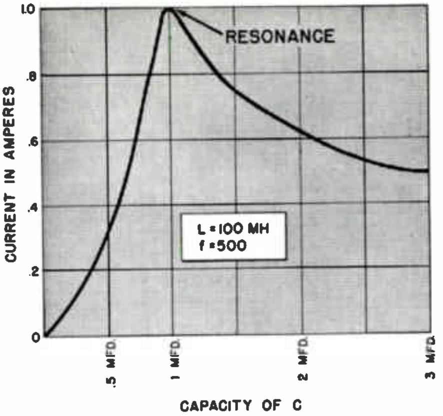


Fig. 8. How current varies in a series-resonant circuit when L is 100 mh, F is 500 cycles, and C is varied from 0 to 3 mfd.

As the capacity is increased above 1-mfd, the capacitive reactance decreases so that the inductive reactance in the circuit is greater than the capacitive reactance. Therefore, the inductive reactance cancels out all of the capacitive reactance and there is still some inductive reactance left over. The circuit begins to act like a circuit having only inductance in it and the current will lag the voltage.

In either case, when the capacity is too small or too high for resonance, the impedance of the circuit is greater than it is at resonance; this accounts for the reduction in current flow in the circuit.

Varying L.

If the inductance in the circuit is varied instead of the capacity, the current will vary as shown in Fig. 9. Here, when the size of the inductor or coil is reduced, the inductive reactance is decreased, and it will not completely cancel out the capacitive reactance in the circuit. The circuit will act like a capacitor, and the current will lead the voltage.

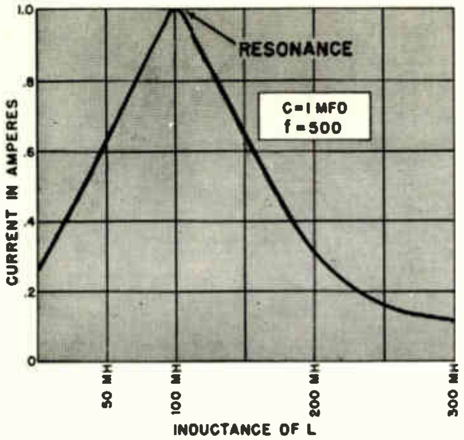


Fig. 9. How current varies in a series-resonant circuit when C = 1 mfd, F = 500 cycles, and L is varied from 0 to 300 mh.

When the inductance is made greater than 100-mh, then the inductive reactance is greater than the capacitive reactance and the circuit will act as an inductance. This means that the current will lag the voltage. Again, the current will be lower than at resonance when the inductance is made either too large or too small because the impedance in the circuit increases. Lowest impedance is obtained in a series-resonant circuit at resonance, when the inductive reactance cancels the capacitive reactance. Current will always be at maximum at this point.

Varying Both L and C.

The combination of a 100-mh coil and a 1-mfd capacitor is not the only combination that will give resonance at 500 cycles. If we double the inductance of the coil by using a 200-mh coil in the circuit, the inductive reactance of the coil will be doubled. It will be twice 315 ohms, or 630 ohms. If we reduce the size of the capacitor from 1-mfd to .5-mfd, we will also double the reactance of the capacitor so that its reactance will now be 630 ohms at 500 cycles. This means that with a 200-mh coil and a .5-mfd capacity, we will again have a situation where the inductive reactance will be equal to the capacitive reactance; therefore, these components will be resonant at 500 cycles.

You can see that many values of coil and capacitor may be used to obtain resonance at 500 cycles. Once we select a coil, it will have a certain inductive reactance at a frequency of 500 cycles. All we need is to obtain a capacitor that will have a capacitive reactance equal to the inductive reactance of the coil at this frequency, and we will have a resonant circuit at 500 cycles.

Varying F.

If we go back to the 100-mh coil and the 1-mfd capacitor and then vary the frequency of the voltage applied to this combination, we will obtain a curve like the one shown in Fig. 10. Notice that in this case we have maximum current flow at resonance, because at resonance the impedance of the circuit is lowest. When the frequency applied to the coil and capacitor combination is less than 500 cycles, the capacitive reactance of the capacitor is greater than the inductive reactance of the coil, so the combination acts like a capacitor and the current will lead the voltage.

When the frequency applied to the combination is above 500 cycles, then the inductive reactance of the coil is greater than the capacitive reactance of the capacitor, and the circuit will act like a coil. In either case, the impedance of the circuit will be minimal at resonance and higher either above or below the resonant frequency. The fact that the impedance reaches its minimum at the resonant frequency of 500 cycles is the reason the current is at maximum.

Varying R.

Under certain circumstances, the total resistance in the circuit may be varied. As the resistance in the circuit is changed, the Q of the circuit changes and the current that will flow in this circuit changes. In Fig. 11, we have shown three resonance curves. The curve marked A is the one we had in Fig. 10 with a 100-mh coil, a 1-mfd capacitor, and a series resistance of 120 ohms. In the curve marked B, the inductance and capacity are the same, but the series resistance is 100 ohms.

Changing the resistance has an important effect on the shape of a resonant curve, as shown in Fig. 11.

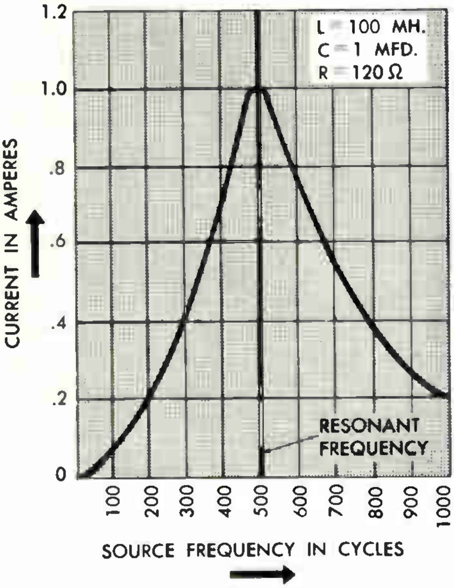


Fig. 10. How current varies in a series-resonant circuit when C = 1 mfd, L = 100 mh, R = 120 ohms, and F is varied from 0 to 1000 cycles.

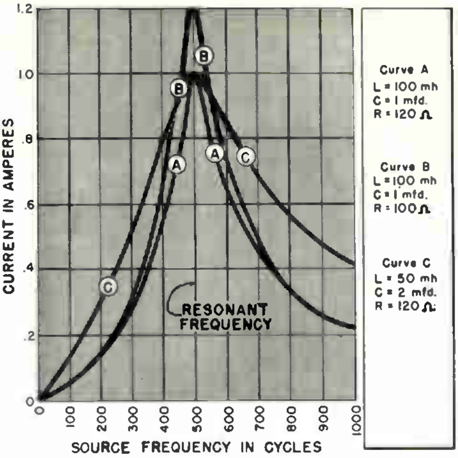


Fig. 11. How the current varies in a series-resonant circuit when F is varied, and (A) C = 1 mfd, L = 100 mh, and R = 120 ohms; (B) C = 1 mfd, L = 100 mh, and R = 100 ohms; (C) C = 2 mfd, L = 50 mh, and R = 120 ohms. In each case the product of L and C is the same, and resonance occurs at 500 cycles.

With a high-Q circuit, which is obtained when the resistance of the circuit is low, we have a very sharp curve. This means that we will get a much higher current flow at the resonant frequency of the circuit than we will get at a frequency either slightly above or slightly below the resonant frequency. However, with a low-Q circuit, we have a broad curve. This means that we can vary the frequency quite a bit either above or below the resonant frequency without causing a very great change in the current that will flow in the circuit.

The effect of resistance on a series-resonant circuit is important. Sometimes a series-resonant circuit may be used to select one frequency and reject all others. Obviously, if we have a high-Q circuit it will do a much better job of selecting one frequency and rejecting others than a low-Q circuit will. However, there are other instances when we are interested in selecting a band of frequencies rather than one particular frequency. In this case, a low-Q series-resonant circuit is used rather than a high-Q circuit which might not select the entire band or group of frequencies in which we are interested.

The curve marked C in Fig. 11 is the one we would obtain with a 50-mh coil, a 2-mfd capacitor and a series resistance of 120 ohms. Compare this curve with curve A. Notice that curve A is considerably sharper than curve C. The ratio of the inductance to the capacity is called the L to C ratio. In a series-resonant circuit a high L to C ratio will give you a sharper resonance curve than a low L to C ratio.

SELF-TEST QUESTIONS

(a) What is a resonant circuit?

(b) What do we mean when we say that the current flowing in the circuit in Fig. 1 is 1 amp?

(c) In a circuit such as the one shown in Fig. 2, why can we not simply add the voltage across the coil and the voltage across the resistor to find the total circuit voltage?

(d) The impedance of a circuit is given as $Z = 50 + j50$; what does the j mean?

(e) In an RC circuit, which part will have the greater voltage across it?

(f) In a series-resonant circuit, how will the phase of the voltage across the various components compare with the phase of the current flowing in the circuit?

(g) What do we mean by the Q of a coil?

(h) When a coil and a capacitor are connected in series, and the frequency of the voltage applied to them is varied, at what point will the current flowing in the circuit reach its maximum value?

(i) What effect on the current flowing in a series-resonant circuit will reducing the resistance in a circuit have?

Parallel-Resonant Circuits

When the source voltage for a resonant circuit is supplied across the coil and capacitor (that is, in parallel with them), as in Fig. 12, we have a parallel-resonant circuit. In a parallel-resonant circuit, as in a series-resonant circuit, the inductive reactance of the coil is exactly equal to and cancels the capacitive reactance of the capacitor. This is essentially where the similarity between the two types of resonant circuits ends. In most respects, a parallel-resonant circuit acts in the opposite way to a series-resonant circuit. Let's investigate the characteristics of this type of resonant circuit and see why it performs as it does.

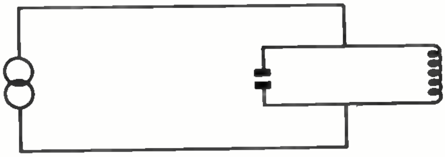


Fig. 12. A parallel-resonant circuit.

CIRCUIT CURRENT AND IMPEDANCE

In Fig. 13 we have shown a parallel-resonant circuit connected in series with a 120-ohm resistor across a 120-volt, 500-cycle generator. The coil has an inductance of 100 mh and the capacitor has a capacity of 1 mfd. All the conditions are as they were when we studied the series-resonant circuit. We have connected an ammeter in series with the resistor and the parallel-resonant circuit, a voltmeter across the coil and capacitor combination, and another voltmeter across the resistor.

In this type of circuit you can notice immediately that the current being supplied by the generator is very low. In addition, the voltage across the resistor is very low and nearly the entire source voltage appears across the resonant circuit.

The fact that the current flowing in the circuit is low immediately points out one important fact -- if the current flowing in the circuit is low, the impedance of the circuit must be high. In fact, this is the case; one of the most important characteristics of a parallel-resonant circuit is that at the resonant frequency it acts as a high-value resistance. Notice that this is just the opposite of a series-resonant circuit: at resonance a series-resonant circuit acts as a low resistance.

The fact that the parallel-resonant circuit acts like a high resistance explains why most of the source voltage appears across the resonant circuit and very little voltage appears across the 120-ohm resistor. The

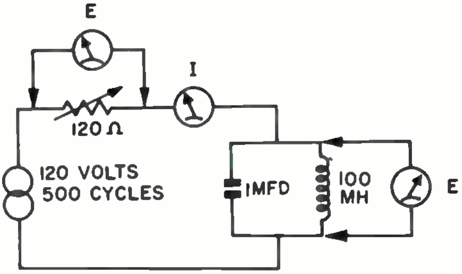


Fig. 13. In a parallel-resonant circuit, the current supplied by the generator is low, and most of the generator voltage appears across the resonant circuit.

120 volts supplied by the generator is simply divided between the resistor and the resonant circuit, with most of the voltage appearing across the higher resistance. Now let's study the parallel-resonant circuit in detail to see why it acts like a high value resistance.

Since the coil and capacitor in the parallel-resonant circuit are connected in parallel, there are two paths or branches through which current can flow. We call the path with the capacitor in it the capacitive branch, and the one with the inductance in it the inductive branch. If we connect an ac ammeter in each branch of the parallel-resonant circuit as shown in Fig. 14, we will discover that although we have a very low current being supplied by the generator, we have a very high current in each branch of the resonant circuit. You might wonder how this could be, but if we consider each branch separately we can see what is happening.

First, in a capacitive circuit we know that the current leads the voltage by 90°; in an inductive circuit the current lags the voltage by 90°. Therefore, the current flowing in the capacitive branch will be 180° out of phase with the current flowing in the inductive branch. The fact that the currents I_1 and I_2 are 180° out of phase means that the capacitor is discharging during one half cycle while the coil stores up electrical energy. During the next half cycle when the coil is releasing the electrical energy it has stored, the capacitor is charging. When the reactance of the coil is equal to that of the capacitor, as it will be at resonance, the energy stored by the capacitor equals the energy released by the coil; and during the other half of the cycle, the energy stored by the coil equals the energy released by the capacitor.

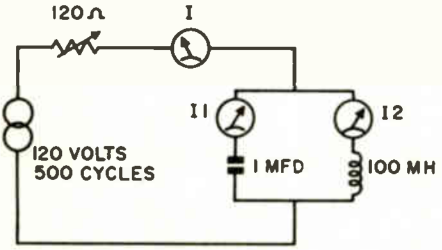


Fig. 14. Although the current supplied by the generator is low, the current flowing in each branch of a parallel-resonant circuit is high.

Thus the coil and the capacitor pass current back and forth to each other inside the resonant circuit. The actual amplitude of the current will depend upon the amount of resistance in the circuit. You know that the coil will have some resistance, and in addition, the leads connecting the coil and capacitor together have some resistance. However, because the resistance is usually kept quite low there can be a very high current flowing back and forth between the coil and the capacitor.

The fact that there is resistance in the circuit means that there will be some energy lost during each cycle. The very low current being supplied by the generator actually replaces the energy lost as heat because of the resistance in the resonant circuit.

The situation in the parallel-resonant circuit may be compared to the pendulum of a clock. The pendulum swings back and forth, and the current does essentially the same thing; it flows out of the coil into the capacitor and then back from the capacitor into the coil. If the pendulum in a clock were swinging freely, it would lose energy each oscillation due to friction and each arc would be smaller than the previous one; finally, it would come to rest. In a parallel-resonant circuit the current will flow back and forth and get smaller each cycle and eventually drop to zero unless some outside energy is supplied to it. The mechanical drive in the clock supplies the energy to the pendulum to keep it swinging; in the resonant circuit, the generator across the circuit supplies the energy to make up the losses in the circuit. Once the action of the current flowing back and forth in a parallel-resonant circuit has started, it will continue for a number of cycles until all the energy is used up in the resistance in the circuit. Similiarly, the pendulum of a clock will swing back and forth for a number of cycles once it is started in motion even if no additional energy is supplied to it.

The situation we have found in the parallel-resonant circuit exists at all times when a coil and capacitor are connected in parallel in an ac circuit. One feeds energy or current back into the circuit while the other draws current. Therefore, the current supplied by the generator at any instant will be the difference between the two currents. When the reactances are equal, as they are at resonance, then this current becomes the minimum current needed to make up the losses in the parallel-resonant circuit. Because the current does drop to a minimum value at resonance, the parallel-resonant circuit acts like a resistor of high ohmic value and reduces the line current supplied by the generator to a very low value.

At resonance, the inductive and capacitive currents are equal to each other and opposite in phase. The net result is zero current. Since the current is zero, the circuit acts as a high resistance. The current supplied to a parallel-resonant circuit by the generator will be in phase with the generator voltage. The actual resistance of the parallel-resonant circuit can be obtained by measuring the voltage across it and dividing it by the current supplied by the generator. This effective resistance is known as the resonant resistance of the circuit.

There is a resonant voltage step-up in a series-resonant circuit. This is not the case, however, in a parallel-resonant circuit since the coil and the capacitor are connected in parallel. The current flowing between the coil and the capacitor is much higher than the current supplied by the generator. Therefore, we have a resonant current step-up in a parallel-resonant circuit. In a high-Q circuit of the latter type, the current flowing back and forth may be many times the line current.

VARYING R, L, C, AND F

Varying R.

You will remember that all coils have a certain amount of resistance which gives the effect of a resistor connected in series with the coil. This resistance can be changed by changing the size of the wire used to wind the coil while at the same time keeping the inductance of the coil constant.

If we use a circuit like the one shown in Fig. 15 to study the effect of varying the resistance in series with the coil, we will find that with the resistance set at a minimum, the coil current is equal to the capa-

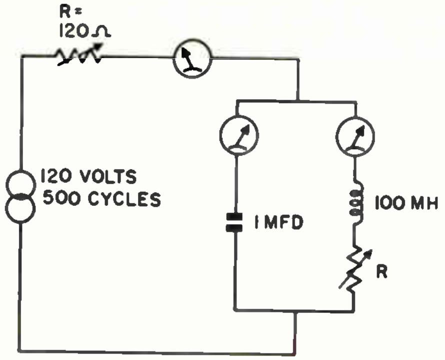


Fig. 15. Increasing R will increase the line current, which means that the resonant resistance of the resonant circuit has decreased.

citor current, and that the line current is very low. If we increase the value of the resistance R, the coil current will decrease slightly and the capacitor current will remain the same, but the line current will increase. This means that the resonant resistance of the parallel-resonant circuit must decrease in order for the line current to increase. From this we can see that the lower the coil resistance in a parallel-resonant circuit, the higher the resonant resistance and the lower the line current will be.

We mentioned earlier that once the current starts flowing back and forth in a parallel-resonant circuit, it will continue for a number of cycles even though the generator voltage may be removed. How quickly the current flowing in the circuit drops to zero depends upon the resistance in the circuit. If the resistance in the circuit is high, the energy in the circuit will be dissipated quickly in the resistor and the current will drop to zero in a few cycles. On the other hand, if the resistance in the circuit is very low, there will be very little energy lost each cycle and the back and forth action of the current may continue for a large number of cycles.

Varying C.

In the parallel-resonant circuit with a 100-millihenry coil, we will obtain resonance at 500 cycles when the capacity in parallel with the coil is 1 mfd. The line current will be minimal at this point.

If we set R to zero and try different values of capacitors in parallel with the coil, recording the line current for each capacitor, we could obtain the data to plot a curve like the one shown in Fig. 16. Notice that at resonance the line current drops to a low value. When the capacity is less than 1 mfd, the current rises until it is about .35 amp at zero capacity. Under these circumstances, with no capacity in parallel with the coil, the current flowing in the circuit will be limited by the inductive reactance of the coil and the amount of resistance in the circuit.

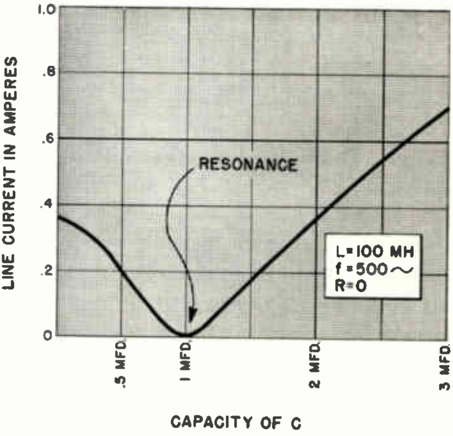


Fig. 16. How the line current varies when the capacity of the capacitor in a parallel-resonant circuit is varied.

When the capacity is reduced to zero, we have a circuit like the one in Fig. 2. However, as capacity is placed in parallel with the coil, the line current begins to drop until finally at resonance it is practically zero.

As the capacity is increased beyond 1 mfd, its reactance decreases, so you will find that the capacitor current will start to increase, the line current will increase, and the coil current will remain essentially unchanged. Here the increase in line current is due to the fact that the capacitor current becomes greater than the coil current and hence part of the capacitor current must be drawn from the line.

When the capacity is less than that required for resonance, the increase in line current is due to the fact that the coil current is greater than the capacitor current and part of the coil current must be drawn from the line.

It is interesting to note that when the capacity in the circuit is .5 mfd, the current is considerably higher than it was when the circuit was at resonance. This is because the capacitive reactance in the circuit is considerably higher than the inductive reactance. If the frequency applied to the circuit were increased, the inductive reactance would increase, and the capacitive reactance would decrease. By increasing the frequency by the correct amount, we could eventually reach the point where the inductive reactance would be equal to the capacitive reactance of the .5 mfd capacitor; once again we would have resonance.

Varying L.

If we put different coils in the circuit, while at the same time keeping the source frequency at 500 cycles, we will find that we have an effect somewhat similar to the effect of changing the value of the capacitor. The line current will be increased when the inductance is made either too large or too small for resonance. If the inductance is below the value needed for resonance, the circuit will act exactly as it did when too low a capacity was used; when the inductance is too high for resonance, the circuit will act as it did when the capacity was too high.

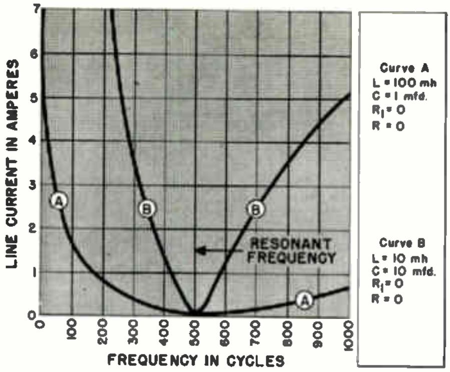


Fig. 17. How the line current varies when the frequency is varied in a parallel-resonant circuit.

Varying F.

In Fig. 17 we have a graph that shows how the line current will vary as the frequency applied to the resonant circuit is changed, if both resistors are set at zero. If we started with 0 cycles, which is dc, we would have a very high current. At this frequency there would be no current through the capacitor, and the inductive reactance of the coil would be zero. The only thing limiting the current flow in the circuit would be the resistance of the coil and of the leads used to connect it to the voltage source. However, as the frequency applied to the circuit increases, the line current drops until at 500 cycles the current is practically zero. As the frequency is increased beyond resonant frequency, the current will increase slowly. The increase in line current is due to the drop-off in the capacitive reactance of the capacitor. Current flowing through the coil will continue to decrease as the frequency is increased, because the inductive reactance of the coil will increase with the frequency.

At a frequency below the resonant frequency of the circuit, most of the current flows through the coil, and hence the parallel-resonant circuit acts as a coil. Right at resonance the circuit acts as a very high resistance, and above the resonant frequency the current flowing through the capacitor will be greater than the current flowing through the coil; hence, the resonant circuit will act as a capacitor.

The curve marked A in Fig. 17 represents an inductance of 100 mh and a capacity of 1 mfd. This circuit is resonant at 500 cycles, because the inductive reactance of the coil is equal to the capacitive reactance of the capacitor at this frequency. However, if we reduce the inductance to 10 mh and increase the capacity to 10 mfd, we will again have a situation where the inductive reactance is equal to the capacitive reactance at 500 cycles. In other words, a 10-mh coil will form a parallel-resonant circuit with a 10 mfd capacitor at a frequency of 500 cycles. The curve we would obtain by varying the frequency of the voltage applied to the parallel-resonant circuit made up of the 10-mh coil and the 10-mfd capacitor is represented by curve B in Fig. 17. Notice that the current rises much faster on both sides of resonance and drops to zero much more sharply than the curve for the 100 mh coil and the 1 mfd capacitor. We say that curve B is sharper than curve A. Curve A was obtained with one LC ratio: a 100 mh coil and a 1 mfd capacitor. Curve B was obtained with another LC ratio: a 10-mh coil and a 10-mfd capacitor. The LC ratio for curve A is higher than the LC ratio for curve B. A low LC ratio gives a sharp curve. This is an important thing to remember.

A low LC ratio is essential if a parallel-resonant circuit is to be used to separate signals having nearly the same frequency (for example, in radio receivers where stations operating on frequencies close together must be separated). If the resonant curve is sharp, we can tune in the desired signal and reject the undesired signals. However, if the resonant curve is broad, as the curve marked A in Fig. 17, it will be difficult to separate the undesired signals from the desired one.

The Q of a coil is another factor that will effect the sharpness of the resonance curves. A high-Q coil will yield a much sharper response curve than a low-Q coil.

In a series-resonant circuit, we obtain a sharp response curve with a high LC ratio. We have the opposite situation in a parallel-resonant circuit, however: we obtain a sharp curve with a low LC ratio.

SELF-TEST QUESTIONS

(j) How do you distinguish between a series-resonant and a parallel-resonant circuit?

(k) What does a parallel-resonant circuit act like at resonance?

(l) Does the generator supply a current of high value or of low value to a parallel-resonant circuit?

(m) In circuits such as the one shown in Fig. 13, why will the voltage across a 120-ohm resistor be small?

(n) Does a current of high value or low value flow in the coil and capacitor in a parallel-resonant circuit?

(o) Will increasing the resistance of the coil in a parallel-resonant circuit cause the generator current to increase or to decrease?

(p) If a parallel-resonant circuit is used in a radio receiver to select one signal and reject others, do you want a high LC ratio or a low LC ratio?

Comparison of Series-Resonant And Parallel-Resonant Circuits

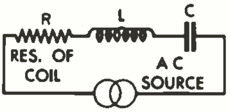
Series-resonant and parallel-resonant circuits are found in every radio and TV receiver and in many other pieces of electronic equipment. Resonant circuits are used in receiving equipment to separate the stations operating on different frequencies and in transmitting equipment in conjunction with vacuum tubes and/or transistors to generate radio frequency signals.

The chart shown in Fig. 18 compares and summarizes the important characteristics of series-resonant and parallel-resonant circuits. Notice that in many cases a series-resonant circuit is the exact opposite of a parallel-resonant circuit. Perhaps the most important characteristics of the two types are the resistance at resonance and the current at resonance. A series-resonant circuit acts as a low resistance at resonance and the current flowing through it will be at its maximum value. On the other hand the parallel-resonant circuit is exactly the opposite, so that at resonance it acts as a very high resistance and the line current flowing through it will be at its lowest value.

RESONANCE CURVES

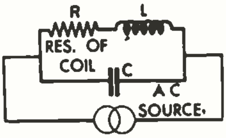
In Fig. 17 you saw that we used a small inductance and a large capacity to obtain a sharp resonance curve with a parallel-resonant circuit. This gave us a low LC ratio. For a sharp resonant curve in a series-resonant circuit you should use a high LC ratio; in other words, you should use a large inductance and a small capacity. This is simply another example of the difference between series-resonant and parallel-resonant circuits. As a technician you will not be called upon to design a series-resonant or a parallel-resonant circuit, but the more you understand about the circuits the better you will be able to maintain the equipment for which you may be responsible.

SERIES-RESONANT CIRCUITS



1. The coil, the capacitor and the AC voltage source are all in series.
2. Resonance occurs when the reactance of L is equal to the reactance of C.
3. At resonance, source current is a *maximum* (very high).
4. At resonance, a series resonant circuit acts like *a resistor of low ohmic value.*
5. At resonance, the voltages across L and C are equal in magnitude but 180 degrees out of phase with each other.
6. At resonance, the same current flows through the entire circuit.
7. At resonance, the voltage across either L or C may be greater than that of the source, giving resonant voltage step-up.
8. At resonance, increasing the value of coil resistance R lowers the circuit current, thereby *lowering* the resonant voltage step-up.
9. Off resonance, the circuit acts like that part which has the *higher* reactance.
   - a. Increasing C above its at-resonance value makes the circuit act like a coil.
   - b. Reducing C below its at-resonance value makes the circuit act like a capacitor.
   - c. Increasing L above its at-resonance value makes the circuit act like a coil.
   - d. Reducing L below its at-resonance value makes the circuit act like a capacitor.
   - e. Applying a *higher* frequency than the resonant one makes the circuit act like a coil.
   - f. Applying a *lower* frequency than the resonant one makes the circuit act like a capacitor.
10. The product LC is constant for any given resonant frequency.
11. Increasing L or increasing C lowers the resonant frequency.
12. Decreasing L or decreasing C raises the resonant frequency.
13. The Q factor of the circuit is essentially equal to the coil reactance divided by the AC resistance of the coil.

PARALLEL-RESONANT CIRCUITS



1. The coil, the capacitor and the AC voltage source are all in parallel.
2. Resonance occurs when the reactance of L is equal to the reactance of C.
3. At resonance, source current is a *minimum* (very low).
4. At resonance, a parallel resonant circuit acts like *a resistor of high ohmic value.*
5. At resonance, the voltages across L, C and the source are all the same in magnitude and phase.
6. At resonance, the currents through L and C are essentially equal in magnitude but are 180 degrees out of phase.
7. At resonance, the current through either L or C is greater than the source current, giving resonant current step-up.
8. At resonance, increasing the value of coil resistance R increases line current, thereby *lowering* the resonant current step-up.
9. Off resonance, the circuit acts like that part which has the *lower* reactance.
   - a. Increasing C above its at-resonance value makes the circuit act like a capacitor.
   - b. Reducing C below its at-resonance value makes the circuit act like a coil.
   - c. Increasing L above its at-resonance value makes the circuit act like a capacitor.
   - d. Reducing L below its at-resonance value makes the circuit act like a coil.
   - e. Applying a *higher* frequency than the resonant one makes the circuit act like a capacitor.
   - f. Applying a *lower* frequency than the resonant one makes the circuit act like a coil.
10. The product LC is constant in any given resonant frequency.
11. Increasing L or increasing C lowers the resonant frequency.
12. Decreasing L or decreasing C raises the resonant frequency.
13. The Q factor of the circuit is essentially equal to the coil reactance divided by the AC resistance of the coil.

Fig. 18. Comparison of series-resonant and parallel-resonant circuits.

DISTINGUISHING BETWEEN SERIES AND PARALLEL-RESONANT CIRCUITS

Sometimes, it is not easy to distinguish between a series-resonant and a parallel-resonant circuit. In Fig. 19A we have shown a series-resonant circuit. A series-resonant circuit is a resonant circuit in which the source voltage has been applied to the coil and capacitor in series. There is no doubt that this is a series-resonant circuit.

In Fig. 19B we have shown a parallel-resonant circuit. The parallel-resonant circuit is a resonant circuit in which the source voltage has been applied to the coil and capacitor in parallel. Again, it is easy to see that this is a parallel-resonant circuit.

Fig. 19C shows two resonant circuits that again look like two parallel-resonant circuits. Here, the secondary is inductively coupled to the primary. Let's look at the primary first. The voltage source is applied to the coil and capacitor in parallel; there is no doubt that the primary is in a parallel-resonant circuit. But how about the secondary? Since the coil and capacitor are connected in parallel you might jump to the conclusion that this is a parallel-resonant circuit, too. Actually, this has no bearing--how the voltage is applied to the circuit determines whether the circuit is a series-resonant or parallel-resonant circuit.

The voltage is induced in the secondary. Actually, some voltages are being induced in each turn of the coil and they act as if they are connected in series, so that the total voltage induced in the secondary is the sum of the voltages induced in each turn. We can compare this to a number of small generators connected in series with the various turns of the coil, and the coil might look like Fig. 19E.

Thus, the voltage induced in the coil is actually applied in series with the turns of the coil rather than in parallel with the coil and the capacitor and could be represented by Fig. 19D (which is the same as Fig. 19A). Therefore, the secondary of the transformer shown in Fig. 19C is a series-resonant circuit and not a parallel-resonant circuit.

You will run into this type of double-tuned circuit in many pieces of electronic equipment. It is often used between two stages in a radio receiver or a television receiver as shown in Fig. 20. Here the primary is connected between the plate of one tube and B+. The secondary is connected between the grid and the cath-

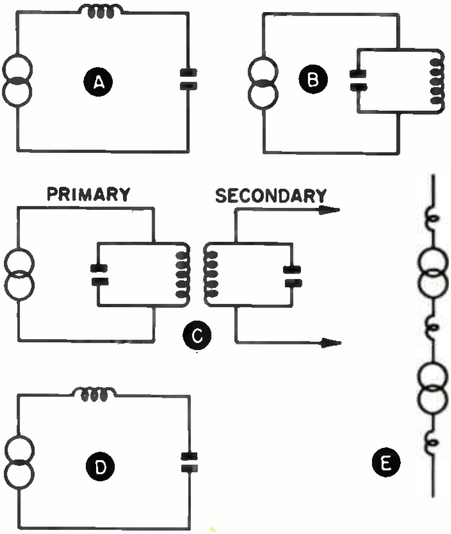


Fig. 19. A series-resonant circuit is shown at A, and a parallel-resonant circuit is shown at B. In C, the primary of the transformer and the capacitor across it form a parallel-resonant circuit, and the secondary of the transformer and its capacitor form a series-resonant circuit.

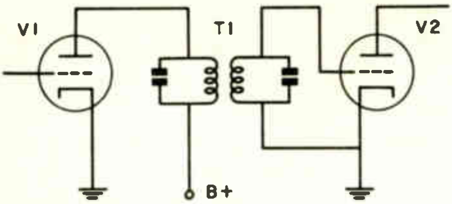


Fig. 20. The primary of T1 is a parallel-resonant circuit, but the secondary is a series-resonant circuit.

ode of the second tube. The tube marked V1 really acts as a generator and supplies the ac signal across the primary of the transformer. A signal is induced in series with the secondary winding, because the secondary is inductively coupled to the primary. Because the coil and capacitor in the secondary form a series-resonant circuit, there is a high current flow with resulting resonant voltage step-up so that this stepped up voltage is applied between the grid and the cathode of V2.

The resonant voltage step-up that occurs in the secondary winding of T1 is quite important. Actually, the primary and secondary windings of T1 will have the same number of turns in most cases. Therefore, you would expect the voltage induced in the secondary to be approximately equal to the voltage across the primary. This is what would happen if we simply had a transformer in the circuit. However, since there are capacitors across each coil and since each circuit is a resonant circuit we have the resonant voltage step-up which occurs in the secondary winding due to the high current flowing in the series-resonant circuit. Thus, there is actually a step-up in voltage occurring in the transformer even though the turns-ratio may be one to one. This means that the signal voltage available between the grid and cathode of V2 will be considerably greater than the voltage between the plate and ground of V1.

SELF-TEST QUESTIONS

(q) Explain the difference between the current flowing in the coil and capacitor in a series-resonant circuit and the current flowing in the coil and capacitor in a parallel-resonant circuit.

(r) Explain the difference between the voltage across the coil and capacitor in a series-resonant circuit and the voltage across the coil and capacitor in a parallel-resonant circuit.

(s) What is the difference between the generator current in a series-resonant circuit and in a parallel-resonant circuit?

(t) How can the voltage across the coil or capacitor in a series-resonant circuit be greater than the source voltage?

(u) What happens if we increase the value of inductance or capacitance in a resonant circuit?

(v) Will the voltage across the coil or the capacitor in a high-Q series-resonant circuit be greater than the voltage across the coil or capacitor in a low-Q series-resonant circuit?

(w) Reducing L below its at-resonance value in a series-resonant circuit makes the circuit act as a capacitor; reducing L below its at-resonance value in a parallel-resonant circuit makes the circuit act as a coil. Explain why this happens.

How Resonant Circuits Are Used

Resonant circuits have many applications. In this section of the lesson we will look into some of the more common uses of resonant circuits in radio and TV. These uses are important because they demonstrate how resonant circuits are used to select one signal from a number of signals of different frequencies.

SELECTING A DESIRED SIGNAL

The antenna connected to a radio or a TV receiver picks up signals from a large number of radio and TV stations. Even the antennas installed especially for television receivers will pick up a certain amount of signal from radio broadcast-band stations. This happens even though the antenna is designed for operation on a much higher frequency than that of the broadcast-band station. Therefore, some means must be provided inside the receiver to select the desired signal and reject the unimportant one. Resonant circuits are used for this purpose.

In Fig. 21 we have shown the input circuit of a radio receiver. The signals picked up by the antenna cause a current to flow through the primary winding L1 of T1. T1 is called an antenna coil or transformer because the signals from the antenna are applied to this coil. The secondary L2 of T1 is inductively coupled to the primary so that the current flowing in L1 sets up a magnetic field which cuts L2 and induces a voltage in it. Remember that when a voltage is induced in a coil in this way, there is a certain amount of voltage induced in each turn of the coil. The voltage induced in the coil acts like a number of generators connected in series with the coil. Thus L2 and capacitor C1 form a series-resonant circuit at some frequency within the broadcast band.

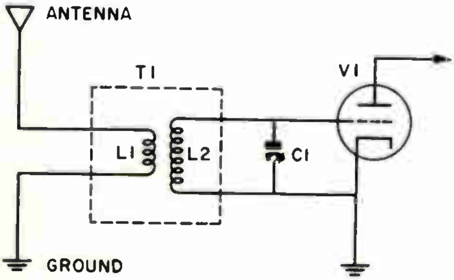


Fig. 21. The input circuit of a typical radio receiver.

Notice the symbol used for the capacitor C1. This symbol indicates that the capacitor is variable. Thus, by changing the setting of C1, the frequency at which the combination of L2 and C1 is resonant can be changed.

Let us suppose that the antenna is picking up two signals of equal amplitude or strength, one having a frequency of 500 kc and the other having a frequency of 800 kc. If the combination of C1 and L2 is resonant at 800 kc (C1 and L2 thus forming a series-resonant circuit), there will be a high 800-kc current through L2 and C1, with resultant step-up voltages appearing across L2 and C1. These voltages are applied between the grid and the cathode of V1 to be amplified by this tube.

At the same time there is a 500-kc signal being picked up by the antenna. This will flow through the primary of transformer T1 and will induce a certain voltage in L2. Since the combination of L2-C1 is not resonant at 500 kc, the impedance of this series circuit will be much higher at 500 kc than it was at 800 kc. This means that the 500-kc current flowing through the series circuit will be low so that voltage developed across L2 and across C1 by this current will be low. Therefore, the 500-kc signal applied between the grid and the cathode of V1 will be much lower in amplitude than the 800-kc signal. Thus, although one resonant circuit is not able to reject the 500-kc signal completely, the amplitude of this signal (when applied between the grid and the cathode of V1) is lower than the amplitude of the desired 800-kc signal that is applied to this tube.

Better selectivity can be obtained in a receiver by using several resonant circuits. If each circuit is tuned to the desired frequency, the difference in signal strength between the desired and the undesired signals will become greater. If enough resonant circuits are used the only signal actually heard in the output of the receiver will be the signal from the desired station.

I-F Transformers.

Most modern radio and television receivers use the superheterodyne principle. In the superheterodyne receiver the signal is picked up by the antenna and fed to a stage called a mixer or first detector. Here, the signal is mixed with a signal generated by the oscillator stage. The two signals mixed together produce two new signals, one equal to the sum of the two frequencies and the other equal to the difference of the two. Both new signals contain the modulation on the original signal. In a superheterodyne receiver we use the difference-frequency signal. In the output circuit of the mixer stage we use a transformer called an intermediate frequency transformer (usually abbreviated as an i-f transformer). This transformer is tuned to resonance at the difference frequency. One or more amplifier stages (called i-f amplifiers) are used to amplify the difference signal. I-F transformers are used between the mixer and the various stages in the i-f amplifier and between the last i-f amplifier stage and the stage called the second detector. The latter separates the audio or picture signals from the rf carrier. Resonant circuits are used in i-f transformers.

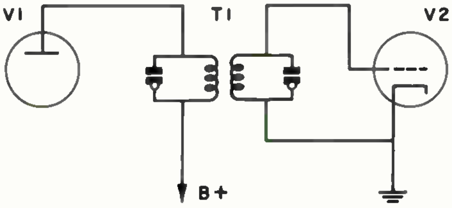


Fig. 22. Coupling between the mixer and the i-f tube in a superheterodyne receiver.

The schematic of a circuit used between the mixer and first i-f stage in a superheterodyne receiver is shown in Fig. 22. The tube marked V1 is the mixer; the tube marked V2, the i-f tube.

You have already seen this type of circuit earlier in the lesson. You know that the primary of T1 is a parallel-resonant circuit because the tube acts as a generator and applies the signal in parallel with the resonant circuit. This parallel-resonant circuit acts as a high resistance at the resonant frequency and the voltage developed by the tube will be high. At frequencies

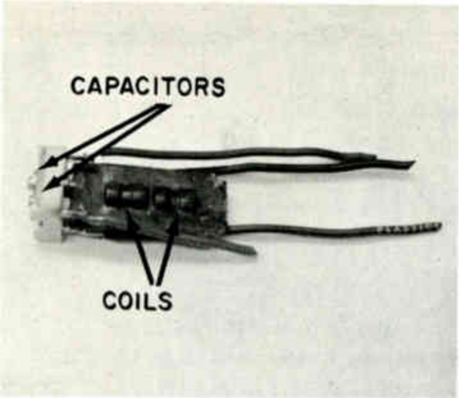


Fig. 23. The inside of an i-f transformer.

other than the resonant frequency, the primary circuit of T1 does not act as a high resistance; as a matter of fact, it acts as a fairly low impedance, so the voltage developed at these frequencies by V1 is low.

The primary of T1 is inductively coupled to the secondary winding so that the secondary circuit is a series-resonant circuit. Again at the resonant frequency, a high current flows and there is considerable resonant voltage step-up across the coil and across the capacitor. These stepped-up voltages are applied between the grid and the cathode of the i-f stage.

A typical i-f transformer is shown in Fig. 23. Notice that the two coils are placed near each other so that the primary and secondary are inductively coupled together. At the top of the transformer are two trimmer capacitors. The adjusting screws on these capacitors can be reached through holes in the top of the i-f transformer can or shield and can be adjusted for exact resonance after they have been installed in the circuit.

A modern superheterodyne receiver uses at least two i-f transformers like the one shown in Fig. 23. The selectivity of two transformers in conjunction with the selectivity obtained in other circuits will make the receiver selective enough so that it will pick up the desired signal even in the crowded broadcast band and in most cases reject the signals from undesired stations.

High-Frequency Circuits.

In some high frequency applications you might find a circuit like the one shown in Fig. 24. The symbol beside the coil indicates that the coil has a slug which can be adjusted in and out of the coil. This will change the inductance of the coil.

Although no capacitor is shown in the circuit, the circuit is actually a parallel-resonant circuit. The tube has a certain capacity between plate and ground, and this capacity will be in parallel with the coil. At high frequencies this capacity, along with the coil, is all that is needed to form a resonant circuit. Circuits of this type are frequently found in television receivers.

In some applications the coil may consist of less than one turn of a flat ribbon-type material such as

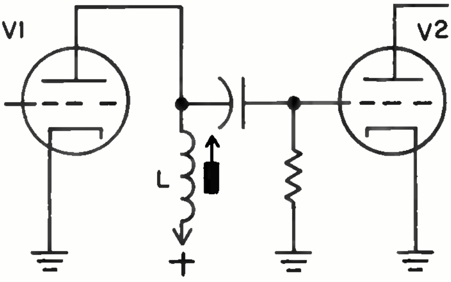


Fig. 24. Coil L in the plate circuit of V1 along with the circuit capacities form a parallel-resonant circuit.

shown in Fig. 25. This type of coil is used in UHF TV circuits and although the inductance in the circuit is extremely small, due to the fact that the circuit must operate at several hundred megacycles, this inductance is all that is required. As a matter of fact, in resonant circuits designed for UHF operation, the problem is not in getting the needed inductance and capacitance, but rather in keeping the inductance and capacitance low enough to produce resonance at the ultra-high frequency desired.

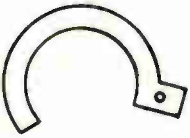


Fig. 25. A single turn of flat ribbon is all the coil that is needed in UHF circuits.

HOW DIFFERENT TYPES OF FILTERS ARE USED

Another important use of resonant circuits is in the design of filters. There are three different types of filters that you are likely to encounter as a technician. The explanation of exactly how each type works is rather complex, and since you need not know how each type of filter operates, we will not go into an explanation here. However, it is important that you know how the different types of filters are used.

Low-Pass Filters.

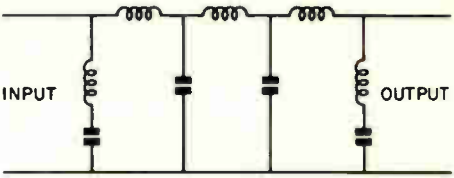


Fig. 26. A low-pass filter.

In Fig. 26 we have shown a schematic diagram of a low-pass filter, which is a filter that will allow signals below a certain frequency to pass through it with little or no attenuation, which means weakening of signals above this specific frequency. For example, if a low-pass filter is designed to pass frequencies below 10 megacycles, it will pass all frequencies from zero cycles per second, which is dc, up to 10 mc with little or no opposition. However, a signal with a frequency of 15 mc, or 25 mc, or in fact any frequency above 10 mc, will encounter a great deal of opposition in going through the filter.

High-Pass Filters.

A high-pass filter is designed to cut off all frequencies below a certain frequency and allow signals above this frequency to pass through with little or no attenuation. A schematic of a typical high-pass filter is shown in Fig. 27.

High-pass filters are often used on TV receivers to eliminate interference from stations operating on frequencies below the television channel. High-pass filters designed for this purpose are available commercially.

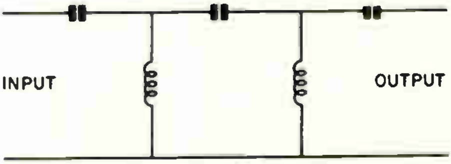


Fig. 27. A high-pass filter.

Band-Pass Filters.

Another type of filter is shown in Fig. 28. This type of filter, called a band pass filter, allows a certain band of frequencies to pass through it with little or no attenuation but offers considerable opposition to signals above and below the frequency of the band to be passed.

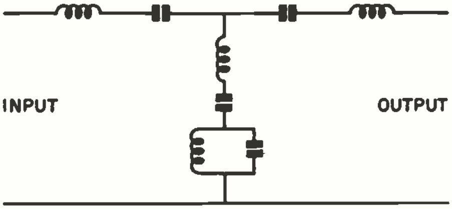


Fig. 28. A band pass filter.

For example, if a band pass filter is designed to have a band width of 2 megacycles, and the center of the pass band is 10 megacycles, then the band pass filter will pass frequencies from 9 mc to 11 mc with little or no attenuation. However, a signal having a frequency of 7 mc, which is below the pass band, or a signal having a frequency of 15 mc, which is above the pass band, will encounter considerable opposition going through the band pass filter.

SUMMARY

In this section of the lesson we have covered a few of the most important uses of resonant circuits. Resonant circuits are used in radio and TV receivers to select one desired signal and reject others. Both series-resonant and parallel-resonant circuits are used in the input stages of a receiver. They are also used between the mixer and i-f stages and between the i-f stage and the second detector.

Resonant circuits are used in filters. A low-pass filter is a filter which will pass frequencies below a certain frequency with little or no attenuation but offers high attenuation to signals above this frequency. A high-pass filter is a filter that will offer little or no attenuation to signals above a certain frequency, but offers high opposition or attenuation to signals below this frequency. A band pass filter will pass a certain band of frequencies, but attenuate signals either above or below the band of frequencies which it is designed to pass.

SELF-TEST QUESTIONS

(x) Is the resonant circuit made up of C1 and L2 in Fig. 21 a series-resonant circuit or a parallel-resonant circuit?
(y) What is a low-pass filter?
(z) What is a high-pass filter?
(aa) What is a band pass filter?
(ab) What type of circuit is used in making up filters?

RC Circuits

Another type of circuit that is extremely important in electronics work is the RC circuit, so called because it contains resistance and capacity. There are several types of RC circuits.

An RC circuit is used as a coupling circuit. This type of circuit is designed to pass a signal through it without changing the shape of the signal. Circuits of this type are used where an ac signal is mixed with dc. RC coupling circuits are widely used in the audio sections of radio and television receivers between the various stages. An RC coupling circuit used between two tubes is shown in Fig. 29A and an RC coupling circuit used between two transistor stages is shown in Fig. 29B. The purpose of the coupling circuit in each case is to pass the signal from one stage to the other without changing the shape of it; at the same time the circuit keeps the operating voltages from one stage out of the following stage.

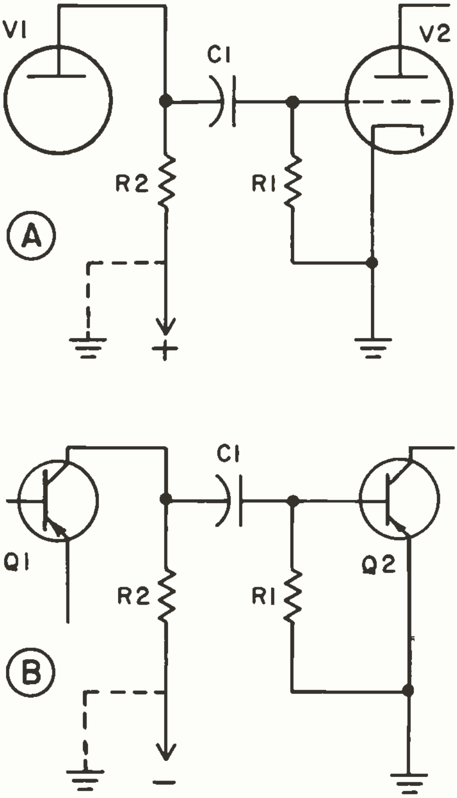


Fig. 29. RC coupling circuits used between tube and transistor stages.

Another type of RC circuit is designed specifically to change the shape of the signal applied to it. This type of circuit is used because the signal being fed through the RC circuit may be used to control the following stage. The shape of the signal may not be the best possible shape to control the stage; by means of a suitable RC circuit, the shape of the wave can be altered. In this section we will study both coupling and wave-shaping circuits, and you will see what they look like, how they work, and where each type is found.

RC COUPLING CIRCUITS

You will run into RC circuits most frequently between stages where they are used to feed the signal from one stage to the next. Typical RC coupling circuits are shown in Fig. 29. The RC coupling circuit in both cases consists of C1 and R1. These are the two components that you will be most concerned with in determining the characteristics of this type of circuit.

The tube V1 in Fig. 29A and the transistor Q1 in Fig. 29B act essentially like an ac generator in RC coupling circuits. One end of resistor R2 is connected to the tube in A and to the transistor in B. The other end is connected to the power supply. However, as far as the ac signal is concerned the end of R2 which is connected to the power supply is in effect connected to ground, because there is a large capacity in the power supply output connected between B+ and ground. This capacitor is so large that it has a very low reactance at all signal frequencies. Therefore the first stage, which is V1 in Fig. 29A and Q1 in Fig. 29B, supplies the voltage to resistor R2. The resistor acts like it is connected between the tube or transistor and ground.

An equivalent circuit of the coupling network is shown in Fig. 30. Here we have represented the tube or transistor as a generator with R2 connected across it. Notice that C1 and R1 are connected in series with each other and this combination is connected in parallel with the resistor R2. The purpose of the coupling network C1-R1 is to feed the signal that is across R2 to the following stage, V2 in Fig. 29A and Q2 in Fig. 29B. If the reactance of C1 is low enough, it will act as a short circuit at signal frequencies so R1 will in effect be connected in parallel with R2. When this situation exists, all the voltage available at the generator output will appear across R1. In other words the voltage appears between the grid and cathode of V2 in Fig. 29A and between the base and emitter of the transistor in Fig. 29B.

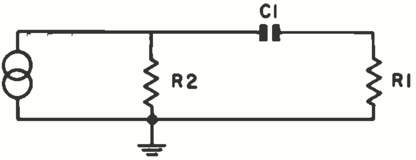


Fig. 30. The equivalent circuit of the RC coupling network shown in Fig. 29.

Capacitor C1 and resistor R1 are in series and they form a voltage divider network. Part of the voltage developed across R2 will be dropped across C1 and part of it across R1. The more voltage there is across R1 the more voltage we have available to drive the second stage. It is therefore important that the reactance of C1 be kept as low as possible in comparison with the resistance of R1. However, regardless of how large the capacitor C1 is, its reactance will eventually become high enough at some low frequency so that an appreciable part of the voltage developed across R1 is lost across C1. At some frequency the reactance of C1 will be equal to the resistance of R1. When this situation occurs 70.7% of the voltage appearing across R2 will be present across R1. You might expect only 50% of the voltage to appear across R1. However, 70.7% is correct because the voltage across R1 is not in phase with the voltage across C1. If the frequency is made still lower, then the percentage of voltage appearing across R1 will be lower.

When the voltage across R1 drops to 70.7% of the generator output, the current flowing through R1 will be only 70.7% of the maximum it would be with the full voltage across R1. When the voltage and current across R1 drop to 70.7%, the power across R1 will decrease to 50%. This point is called the "half-power" point. The amplifier is considered satisfactory in most cases as long as the output does not drop below this point.

Since C1 and R1 form a voltage divider network, we can keep the frequency at which the reactance of

C1 becomes a problem to a fairly low value by making R1 as large as possible. In the tube circuit shown in Fig. 29A, R1 is called a grid leak. Its value is relatively unimportant and a comparatively large resistor can be used. Therefore, even with a fairly small capacitor for C1, the resistance of R1 does not have much importance except at very low frequencies. On the other hand, making R1 too large will upset the operating voltages in the transistor in the circuit shown in Fig. 29B. In fact, the transistor itself affects the circuit so that there is a maximum value resistor that can be used; it is much lower than that used in the tube stage. The capacitor C1 must be of a much higher capacity in the transistor circuit than in the tube circuit to keep its reactance from becoming high enough to drop an appreciable percentage of the voltage.

Capacitor values from .01 mfd to .05 mfd are typical in tube circuits such as in Fig. 29A. In transistor circuits the value of C1 will often be 10 mfd or more.

The importance of avoiding this voltage division can be seen if you consider what happens to signals of different frequencies when they are amplified by the amplifier. If a signal voltage of 1 volt and a frequency of 1000 cycles appears across R2, almost the full 1 volt will appear across R1. But, at a frequency of 100 cycles, somewhat less than 1 volt will appear across R1; at a frequency of 10 cycles, even less will appear across R1. This means that the amplifier will not amplify signals of different frequencies equally. When this situation exists, we say we have frequency distortion. In the average radio receiver, a small amount of frequency distortion is not objectionable, but in high-fidelity equipment and in TV equipment, this type of distortion must be kept at a minimum if satisfactory results are to be obtained.

For the present the important thing you should remember is that an RC coupling circuit has a long time constant. Remember that capacitor C1 and resistor R1 are in series, but that at most frequencies the reactance of C1 is so low compared to the resistance of R1 that it acts as a short circuit and can be ignored. However, at very low frequencies the reactance of this capacitor is appreciable. We will discuss this situation in more detail when you study vacuum tubes and amplifiers.

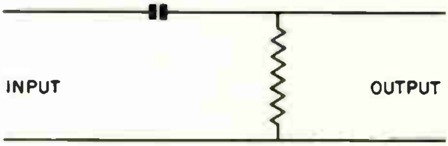


Fig. 31. An RC differentiating circuit.

RC DIFFERENTIATING CIRCUITS

Differentiating circuits are found in TV receivers and in many other pieces of electronic equipment. Fig. 31 shows a circuit of this type -- notice that it looks like a coupling circuit. However, the latter has a long time constant, whereas a differentiating circuit has a short time constant. Because differentiating circuits are normally used with pulses, you should know that a pulse is a variation of a quantity whose value is normally constant.

Fig. 32A illustrates a typical sine wave. Remember that the voltage starts at zero, builds up to a maximum and drops back to zero.

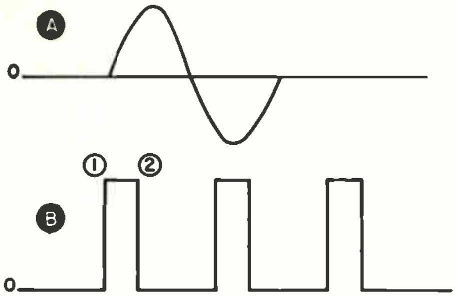


Fig. 32. A single cycle of a sine wave is shown at A, and a group of three pulses is shown at B.

A series of three positive-going pulses is shown in Fig. 32B. Notice that the signal voltage is zero, jumps instantly to its maximum value at point 1, remains constant from point 1 to point 2, and finally drops to zero again at point 2. Let's see what will happen if a pulse of this type is fed to a differentiating circuit such as the one in Fig. 31.

The value of R and of C in the differentiating circuit are chosen with a short time constant so that the capacitor charges and discharges quickly. As the leading edge of the pulse (which we have marked as 1) hits the capacitor there is an immediate current flow through the resistor to charge the capacitor. Since the capacitor has no charge on it at this instant, the current flow as well as the voltage developed across the resistor will be high. As the pulse maintains its constant value, the capacitor charges rapidly, the current flowing in the capacitor decreases and the voltage developed across the resistor falls off. Finally, the capacitor is fully charged, no additional current is flowing and the voltage across the resistor drops to zero.

The capacitor must discharge when the pulse drops from its peak amplitude at point 2 to zero. At the instant the applied voltage pulse disappears the capacitor is charged, although there is no longer a pulse across it. Then it starts to discharge through the resistor and a high current flows through the resistor. Instantly, there is a high voltage across it. The current flows in the opposite direction from that in which it flowed while the capacitor was charging, so the pulse appears in the opposite direction. As the capacitor becomes discharged, the current flowing drops gradually to zero so that the voltage appearing across the resistor also drops to zero.

The reaction of a differentiating circuit to a series of pulses is shown in Fig. 33. At A we have shown the pulse and below it at B the output voltage that will be obtained across the resistor as the pulse varies to a maximum and drops back to zero again.

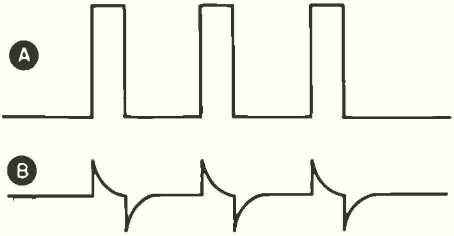


Fig. 33. Input and output signals applied to a differentiating circuit.

Differentiating circuits work in this way because they have a short time constant. The capacitor is able to charge and discharge rapidly, and therefore a double-pointed pulse as shown in Fig. 33 is obtained when a pulse is applied to the input of this type of circuit.

RC INTEGRATING CIRCUITS

A typical RC integrating circuit is shown in Fig. 34. Notice that the parts are connected in a way opposite from that in which they were connected in the differentiating circuit, and that a long time constant rather than a short time constant is used.

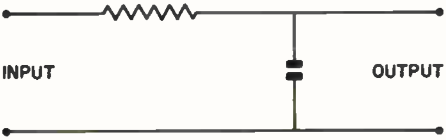


Fig. 34. An integrating circuit.

Fig. 35 illustrates the action of an integrating circuit. The capacitor begins to charge as the first pulse strikes the circuit; it starts to discharge after the first pulse passes but does not discharge completely before the second pulse arrives due to the long time constant. After the second pulse the capacitor starts to discharge again until the third pulse arrives -- then it charges still further. An integrating circuit is thus able to sum up or add a series of pulses to give one pulse in the output. Integrating as well as differentiating circuits are used in TV receivers and in many other pieces of electronic equipment.

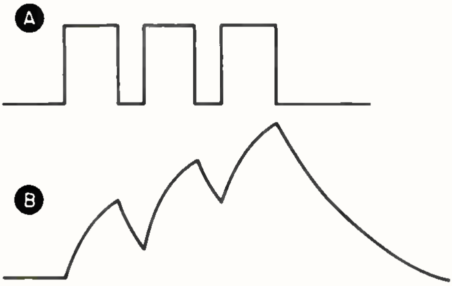


Fig. 35. Integrating circuit action on a series of pulses.

SUMMARY

In this section of the lesson you found that RC circuits can be used in several ways. They can be used as coupling circuits to feed a signal from the plate of one tube to the grid of the next tube. When they are used in this way the purpose is to pass the signal from one tube to the other without distorting or changing it in any way.

RC circuits are also used as differentiating circuits. A differentiating circuit is a circuit that develops a sharp positive and negative pulse from a single pulse. If the pulse supplied to the circuit is a positive-going pulse, which is what we call the pulse shown in Fig. 32B, then the output will be a positive pulse followed by a negative pulse. If the input signal is a negative-going pulse, then the output will be a sharp negative pulse followed by a sharp positive pulse.

An integrating circuit is a circuit that has a long time constant and adds together a number of separate pulses to produce one large pulse in the output.

SELF-TEST QUESTIONS

(ac) What is the purpose of an RC coupling circuit?

(ad) Is the reactance of the coupling capacitor likely to become a problem at high, low, or medium frequencies?

(ae) What do we mean by the half-power point?

(af) What do we mean by frequency distortion?

(ag) What is a differentiating circuit?

(ah) What is an integrating circuit?

LOOKING AHEAD

In this lesson you have seen how resistors, coils, and capacitors are used together to form a number of different types of circuits. By this time you have probably realized the importance of these three components. Before leaving this lesson it is worthwhile to stop and consider the fact that we have all three of these quantities in every circuit.

Even a piece of straight wire has a certain amount of resistance, a certain amount of capacity between it and nearby objects, and also a small amount of inductance. If the frequency of the signal running through the wire is high enough, even these small amounts of resistance, capacity, and inductance may be large enough to merit consideration.

We have brought up this point now because you will soon be working on, repairing, and replacing circuits in equipment which operates at very high frequencies. Because the resistance, capacity, and inductance in circuits operating at these high frequencies is so important, replacement parts should be put as closely as possible in the position occupied by the original part.

In the following lesson you will study additional components that will be important in your electronics career: vacuum tubes, transistors, complete stages and signals. You will also learn how the value of parts used in a circuit affects the performance of the stage.

There are a number of schematic diagrams in this lesson. If you study carefully the diagrams which appear in earlier lessons, complex diagrams in later lessons will not present a problem for you. Difficulties will occur if you wait until later lessons to trace circuits on complex diagrams.

ANSWERS TO SELF-TEST QUESTIONS

(a) A resonant circuit is one in which the inductive reactance cancels the capacitive reactance.

(b) We mean that the rms value or the effective value of the ac current flowing in the circuit is 1 amp. The ac current would have the same heating effect as 1 amp of dc. Remember that an ac current actually drops to 0 twice each cycle and reaches peak values approximately 1.4 times the effective or rms value.

(c) We cannot add the voltages because they are not in phase. The voltage across the resistor will be in phase with the current, whereas the voltage across the coil will lead the current by 90°. We must add these two voltages by means of vectors.

(d) In the expression "j50", the j indicates a reactive component; the 50 (for ohms) represents a reactance rather than a resistance. The plus sign in front of the j means that the reactance is inductive. A minus sign in front of the j indicates capacitive reactance.

(e) The voltage across the parts in an RC circuit will depend upon the parts themselves. If the reactance of the capacitor is greater than the resistance of the resistor then the voltage across the capacitor will be greater than the voltage across the resistor. On the other hand, if the resistance of the resistor is higher than the reactance of the capacitor, the voltage across the resistor will be greater than the voltage across the capacitor.

(f) Across the resistor the voltage will be in phase with the current; across the coil it will lead the current by 90°; across the capacitor it will lag the current by 90°.

(g) The Q of a coil is equal to the inductive reactance of the coil divided by the resistance of the coil. It is indicative of the worth of the coil, which is supposed to have inductive reactance with little or no resistance. Since the coil is wound with wire, however, it will have some resistance. The coil will act more like a resistor as this resistance increases. Therefore, a high-Q coil is better than a low-Q coil.

(h) The current will reach its maximum value when the inductive reactance of the coil cancels the capacitive reactance of the capacitor. When this happens we have a series-resonant circuit.

(i) Reducing the resistance in a series-resonant circuit will cause the current flowing in the circuit to increase. A higher resonant voltage will appear in turn across the coil and the capacitor. The voltage which appears across the resistor will remain the same because the increase in current will be counteracted by the reduction in resistance. Thus, the entire generator voltage will appear across the resistor.

(j) The distinction between a series-resonant circuit and a parallel-resonant circuit lies in the way in which the voltage is applied to the coil and the capacitor. If it is applied to the coil and the capacitor in series, the circuit is series-resonant; if it is applied to the coil and the capacitor in parallel, the circuit is parallel-resonant.

(k) A high value resistance.

(l) The generator connected across a parallel-resonant circuit will supply a current of low value because the high resistance of this type of circuit limits the current which can flow.

(m) The voltage across the resistor will be small because the resistor is in series with the parallel-resonant circuit. Most of the voltage will be dropped across the higher resistor. A parallel-resonant circuit has a very high resistance at resonance and most of the voltage will be dropped across it. Consequently, there will be very little voltage across the 120-ohm resistor.

(n) In a parallel-resonant circuit, a high value current flows in the coil and in the capacitor. These two currents are 180° out of phase. Energy stored in the capacitor flows out of the capacitor into the coil, where it is stored, and then flows from the coil back into the capacitor. This back-and-forth flow of current reaches a very high value. Even though the current actually supplied by the generator is low, it is enough to make up for losses in the resonant circuit due to resistance in the coil and in the wires connecting the coil and the capacitor together.

(o) Increasing the resistance of the coil in a parallel-resonant circuit causes the generator current to increase. More losses occur as a result of increased resistance, and the generator supplies more current to make up for these losses.

(p) A low LC ratio gives a sharper curve such as curve B in Fig. 17. This type of curve is required in order to select one station and reject another. A broad curve such as curve A of Fig. 17 would be unsuitable because stations operating close to the desired station would not be rejected.

(q) In a series-resonant circuit the same current flows in the coil and in the capacitor. As a matter of fact, since the generator, resistance, coil and capacitor are all in series in a series-resonant circuit, the same current must flow through all these components. On the other hand, in a parallel-resonant circuit the current through the coil and capacitor are essentially equal in magnitude, but they are 180° out of phase.

(r) In a series-resonant circuit, the voltage across the coil will be equal to but 180° out of phase with the voltage across the capacitor. In a parallel-resonant circuit the coil and capacitor are connected in parallel and the voltage across the two will therefore be the same.

(s) The generator current in a series-resonant circuit will be very high because this circuit acts as a low resistance. The generator current in a parallel-resonant circuit will be very low because this circuit acts as a high resistance.

(t) The inductive reactance of the coil in a series-resonant circuit cancels the capacitive reactance of the capacitor. Therefore the only factor that limits current flow in the circuit is the resistance in the circuit. This results in a very high current flow. The current flowing through the coil and through the capacitor produces a voltage drop across these components which will be equal to the product of the current times the reactance of the particular part. This product may be greater than the source voltage. The voltage across the coil and across the capacitor are 180° out of phase so that they cancel each other and the entire generator voltage will appear across the resistance in the circuit.

(u) Increasing the value of L or C in a resonant circuit will reduce the resonant frequency.

(v) Yes, the voltage across the coil and capacitor in a high-Q series-resonant circuit will be greater than the voltage across the coil and capacitor in a low-Q series-resonant circuit. This is due to the fact that a higher current will flow in a high-Q circuit which, all other factors being equal, will produce a greater voltage across the coil and across the capacitor.

(w) When we reduce L below its at-resonance value in a series-resonant circuit, the inductive reactance will be less than the capacitive reactance. Therefore the net reactance in the circuit will be capacitive - in other words the inductive reactance cannot completely cancel out the capacitive reactance. It will subtract from it but there will still be capacitive reactance left over, and the circuit will act as a capacitor. The current flowing through the circuit will lead the voltage. On the other hand, when we reduce L below its at-resonance value in a parallel-resonant circuit, the inductive reactance will be less than the capacitive reactance and more current will flow through the lower reactive branch. The net result will be that the capacitive current cannot completely cancel out the inductive current. Therefore, the circuit will act as inductance and the voltage will lead the current.

(x) The resonant circuit is a series-resonant circuit because the voltage is induced in series with the turns of L2. Therefore, the voltage is applied in series with the coil and the capacitor.

(y) A low-pass filter is a filter designed to pass signals below a certain frequency and reject all signals above that frequency.

(z) A high-pass filter is a filter designed to pass all signals above a certain frequency and reject signals below that frequency.

(aa) A bandpass filter is a filter designed to pass a certain band of frequencies with little or no attenuation. It will reject or offer considerable opposition to frequencies above and below the band it is designed to pass.

(ab) Various combinations of series-resonant and/or parallel-resonant circuits are used in making up filters.

(ac) An RC coupling circuit is used to transfer a signal from one stage to another without changing the shape of the signal.

(ad) At low frequencies.

(ae) The half-power point is the frequency at which 70.7% of the voltage appears across the resistor in an RC coupling circuit. At this frequency the current will also have dropped to 70.7% of its maximum value so that the power will be down 50% of its maximum value.

(af) Frequency distortion occurs when the amplifier does not amplify equal signals of different frequencies.

(ag) A differentiating circuit is an RC coupling circuit with a short time constant. A circuit of this type will produce sharp spikes in the output which can be used for controlling stages in a TV receiver.

(ah) An integrating circuit is a circuit with a long time constant that will build a series of pulses up into a single pulse.

Lesson Questions

Be sure to number your Answer Sheet B108.

Place your Student Number on every Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time, or you may run out of lessons before new ones can reach you.

1. What determines whether a resonant circuit is a series-resonant or a parallel-resonant circuit?

2. What is the impedance of a series-resonant circuit having the following component values: $R = 25$ ohms, $X_L = 200$ ohms, $X_C \doteq 200$ ohms?

3. What do we mean by the resonant voltage step-up in a series-resonant circuit?

4. In which type of series-resonant circuit will the resonant voltage step-up be the greatest: (a) a high-Q circuit, (b) a low-Q circuit? Why?

5. What part does a parallel-resonant circuit act like at resonance?

6. What is meant by the resonant current step-up in a parallel-resonant circuit?

7. Which one of the following parts does a parallel-resonant circuit act like below the resonant frequency: (a) a resistor (b) a coil (c) a capacitor?

8. Compare the following characteristics of series and parallel circuits at resonance: (a) resistance at resonance, (b) current at resonance.

9. What is the difference between an RC coupling circuit and an RC differentiating circuit?

10. What is the purpose of an integrating circuit?

YOU HAVE AN AIM IN LIFE

When you enrolled as a student member of the National Radio Institute, you took the first step on your road to success and happiness. You now have a goal for yourself -- you have an aim in life -- you are looking forward to the sort of work you like, the sort of income you want, and the respect and admiration of your friends.

Keep your goal in mind. Never forget it for a moment. Of course you will have your moments of discouragement -- we all have. But if you make a thorough search for the cause of your discouragement, you will most likely find that you ate something which did not agree with you, or were kept awake last night by the neighbor's dog.

Whenever you are tempted to neglect your studies, say to yourself: "I have a goal to reach and I'm going to reach it." Think how unhappy you would be if you did not have this goal. There is nothing as pathetic as a rudderless ship or a man without an aim in life.

Here's to success and happiness -- your goal.

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ACHIEVEMENT THROUGH ELECTRONICS

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TRANSFORMERS, IRON-CORE CHOKES, AND RELAYS

B109

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TRANSFORMERS, IRON-CORE CHOKES, AND RELAYS

B109

STUDY SCHEDULE

By dividing your study into the steps given below, you can get the most out of this part of your NRI Course in the shortest possible time. Check off each step when you finish it.

☐ 1. **Introduction** .... **Pages 1 - 2**
A brief picture of the three magnetic devices you will study in this lesson is given here.

☐ 2. **Magnetic Circuits** .... **Pages 3 - 9**
Here you learn how magnetic quantities are measured, and you study magnetic saturation and iron-core losses.

☐ 3. **Iron-Core Power Transformers** .... **Pages 10 - 17**
In this section you study losses in transformers, turns-ratios of transformers, and power losses.

☐ 4. **Transformers for Specific Application** .... **Pages 18 - 26**
You study audio, rf, i-f, and autotransformers.

☐ 5. **Iron-Core Chokes** .... **Pages 27 - 31**
You study the electrical and physical characteristics of chokes, and learn how they are used.

☐ 6. **Relays** .... **Pages 31 - 36**
The relay is an electric switch. You study several different types.

☐ 7. **Answers to Self-Test Questions** .... **Pages 36 - 40**

☐ 8. **Answer the Lesson Questions.**

☐ 9. **Start Studying the Next Lesson.**

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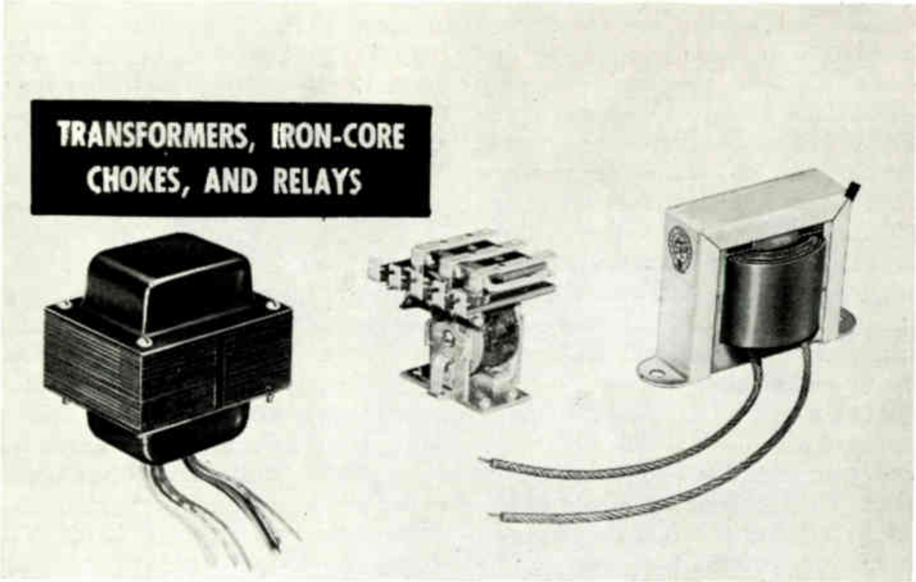
TRANSFORMERS, IRON-CORE CHOKES, AND RELAYS



In this lesson we will take up three very important parts which all operate on magnetic principles; these are: transformers, iron-core chokes and relays.

Transformers.

You already have an idea of how important transformers are. Transformers are used on ac power lines either to step-up or to step-down the voltage. They are used in electronic equipment to supply the high voltage needed to operate the plates of the various tubes in the equipment and to supply the low voltage to heat the tubes. They are used in transistorized equipment to reduce the power line voltage to the voltage required by the transistors.

Transformers have uses other than supplying electric power. They are used in coupling circuits to transmit an audio signal from one stage to another. They are also used in what are called "matching" circuits to connect a device of one impedance to a device of another impedance. An example of this is the output transformer in a radio receiver, which is used to couple the low-impedance speaker to the higher impedance output tube or transistor that drives the speaker. If it were not for the transformer it would be difficult to get enough power from the tube or transistor to drive the speaker.

Transformers are also used in television receivers to transfer the power from the sweep circuits to the deflection yoke. The deflection yoke is used around the neck of the picture tube to move the electron beam over the face of the picture tube to reproduce the television picture. If it were not for transformers, it would be difficult to get the power needed into the deflection yoke to move the beam over the face of the picture tube.

Iron-Core Chokes.

Iron-core chokes are found most frequently in power-supply equipment. Chokes are used to help smooth the pulsating dc found at the output of a rectifier into pure, ripple-free dc. When chokes are used for this purpose, they are called "filter" chokes because they "filter" the ripple or hum out of the pulsating dc. You will see later that this is possible because the reactance of an iron-core choke is much higher than the dc resistance.

Relays.

There are several types of relays that you are likely to meet in your electronics career. One type of relay is nothing more than a form of automatic switch. The relay can be made either to close or to open the switch when power is applied to it.

There are also other types of relays; for example, some are used to protect circuits. This type is adjusted so that if the current flowing through it exceeds a certain value, the relay will automatically open the circuit, thus protecting the device from an overload.

Another type of relay is called a time-delay relay. This kind of relay is often found in electronic equipment where it is important for the heaters of the various tubes to have time to heat before the high plate voltage is applied to the tube. This type of relay is energized when the equipment is turned on. After a predetermined time, the relay operates, closes the circuit, and applies plate voltage to the tubes in the equipment.

Since the parts we'll study are all magnetic devices, before we look into any of them, we will review what you have already learned about magnetic circuits and learn some additional facts about these circuits.

Magnetic Circuits

As we learned previously when we studied magnetic circuits, we can compare them with electric circuits. The force that drives the flux through a magnetic circuit is the magnetomotive force. This force can be compared to the electromotive force that drives current through an electric circuit. The flux that is driven through the magnetic circuit resembles the current that is driven through an electric curcuit.

The opposition to the flux through the circuit can be compared to resistance in an electrical circuit, and is called reluctance.

MAGNETIC UNITS

There are units set up to measure many of the quantities encountered in magnetic circuits. It is not important for you to remember these units, so do not try to memorize them. We are presenting them here, however, so that you will have seen these terms and will have an idea of what they are when you run into them in the future. After you have completed your NRI course, you will have to keep abreast with new developments. In reading the literature on new developments in the electronics field, it is quite possible that you will run into many of these terms.

Units of Magnetomotive Force.

The magnetomotive force is expressed in terms of ampere-turns. If a current of 1 ampere flows through a coil having one turn, the magnetomotive force developed is 1 ampere-turn. If the coil had two turns, then the magnetomotive force would be 2 ampere-turns, and if a current of 2 amperes flows through a two-turn coil, the magnetomotive force will be 4 ampere-turns.

The ampere-turn is an entirely satisfactory term for use in expressing the magnetomotive force of an electromagnet. However, it is not suitable for use with permanent magnets, and for this reason, another unit of magnetomotive force is used. This unit is the gilbert. The gilbert is slightly smaller than the ampere-turn. To convert ampere-turns to gilberts, you multiply the number of ampere-turns by 1.25.

The magnetomotive force is the total force acting throughout the length of the entire magnetic circuit. Sometimes we want to express the magnetic force in terms of the magnetomotive force per centimeter. (The centimeter is a metric unit of measurement. There are about 2.5 centimeters in an inch.) It may be given as gilberts per centimeter. Then, if the length of the magnetic circuit is six centimeters and the magnetomotive force per centimeter is 10 gilberts, the total magnetomotive force would be 60 gilberts. The magnetomotive force per centimeter is called the magnetic force or the magnetizing force.

Units of Flux.

Previously when we were discussing magnetic flux we simply referred to the number of lines of flux. However, there is a term used for this purpose and it is the maxwell. One line of flux is equal to one maxwell. If you have a hundred flux lines, then the strength of the flux is 100 maxwells. Another unit is the kilomaxwell, which is equal to 1000 maxwells.

Another term that you will encounter is flux density. The flux density tells you how many maxwells or lines of flux pass through a given area. Flux density could be expressed in terms of maxwells-per-square-inch, or it could be expressed in terms of maxwells-per-square centimeter. A flux density of 1 maxwell or one line per square centimeter is known as a gauss. Thus if we say that the flux density is 100 gausses, we mean that there are 100 lines for each square centimeter of a cross-sectional area. If you had a magnet that was 3 × 5 centimeters, the total cross-section of the area would be 15 square centimeters. If the flux density is 100 gausses, then the total number of lines flowing would be 15 times one hundred or 1500 maxwells.

Units of Reluctance.

There is no unit of reluctance. Engineers and technicians are more concerned with the permeability of a material, which you might say is the opposite of reluctance. It is the ability of the material to conduct magnetic flux. It is similar to conductivity in an electric circuit, which is the ability of the material to conduct an electric current.

There is no unit of permeability. The permeability of magnetic materials is rated according to how much better the material conducts magnetic flux than air does. The permeability of air and all other non-magnetic materials is given the numerical value of 1. If the permeability of a magnetic material is 2, a magnetomotive force applied to it will produce twice as many flux lines as the same force applied to air. If we say the permeability of a certain magnetic material is 100, we mean that if the magnetomotive force applied to this material was applied to air, and it produced one line or one maxwell in air, then it would produce 100 flux lines or 100 maxwells in the material.

MAGNETIC SATURATION

One very important thing you should know about magnetic circuits is that they can be saturated. This means that they reach a point where all the possible lines of force exist, and increasing the magnetomotive force applied to the circuit will not produce any further increase in flux. Now let's see how this can happen.

A magnetic material such as iron is actually made up of millions of small molecules. A molecule is a tiny particle made up of a combination of two or more atoms. Each of these molecules is actually a small permanent magnet having a north pole and a south pole. When there is no magnetomotive force applied to the material, the molecules are arranged in a helter-skelter fashion as shown in A of Fig. 1. You will notice that the magnets in this material are pointing in all directions; there is no general organization so that all the north poles point in one direction and all the south poles point in another.

Let's see what happens if we apply a magnetomotive force to this material. This can be done by winding a

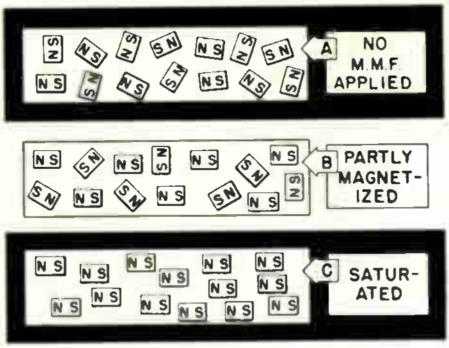


Fig. 1. How the molecules in a material line up as magnetomotive force is applied. Each molecule is like a tiny magnet.

coil around the material and passing a current through the coil. If the current is strong enough to partly magnetize the material, some of the molecules will line up as shown in Fig. 1B. Notice in this figure that there is a general tendency for the north poles to point towards the left and the south poles to point to the right. However, there are a number of molecules that do not follow this general pattern. Some of them are still not lined up.

If we increase the current flowing through the coil or if we increase the magnetomotive force by keeping the current constant and putting more turns on the coil, we will eventually reach a point where all of the molecules are aligned as in C of Fig. 1. Here all the north poles point to the left and all the south poles point to the right. When this situation exists, we say that the material is saturated. This means that any further increase in the magnetomotive force will not produce any further increase in flux. You can see why this is so--all the molecules are already aligned; therefore, it would be impossible to line any more of them up and get more flux. Thus, there would be no point in increasing the magnetomotive force. As a matter of fact, saturation is a condition to be avoided in most cases and if the current is increased beyond the amount needed to align all the molecules, some very undesirable results may occur.

Saturation is sometimes referred to simply as saturation; other times it is referred to as "core saturation" because the magnetic material is usually the core of some device. The magnet may be used as the core of a transformer or a choke. Only magnetic materials can be saturated; an air core cannot be saturated.

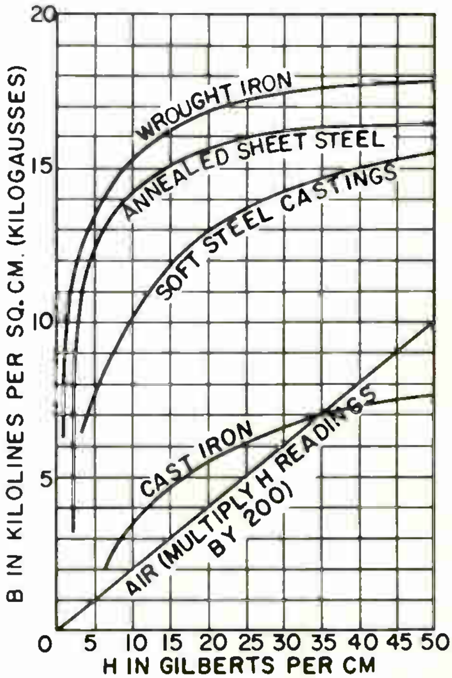


Fig. 2. B-H curves for different magnetic materials.

B-H Curves.

The characteristics of a magnetic material are often represented in the form of a curve called a B-H curve. B-H curves for several different materials are shown in Fig. 2. These curves show the flux density that can be obtained with a given magnetizing force. Notice that as the magnetizing force starts to increase from zero at the left of the graph, the flux density increases quite rapidly at first, then a point is reached where the curve starts to flatten out and it takes a substantial increase in magnetizing force to get even a small increase in flux density. Eventually a point is reached at which the flux density increases no further regardless of how much the magnetizing force is increased. This is the saturation point. However, notice on this graph that the curve for air is a straight line. This simply means that as long as we continue to increase the magnetizing force, the flux density in air will increase. In other words, an air core coil cannot be saturated.

Curves of this type are often used by manufacturers of magnetic materials to describe the characteristics of these materials.

IRON-CORE LOSSES

When we were discussing saturation, we spoke of gradually increasing the current flowing through the coil to increase the magnetomotive force applied to the material. We were discussing a dc current flowing through the coil. Even though we increased the current to show the effects of saturation, the current was still flowing in the same direction. However, we are greatly concerned with the action of coils when alternating current flows through them and the effect the ac has on the magnetic circuit. One of the important things to consider when dealing with alternating current is the losses produced in the iron-core itself.

Hysteresis.

Suppose we apply dc to a coil which in turn produces a certain magnetizing force. As the magnetizing force increases, the flux density increases, as shown by the curve A in Fig. 3, following a curve such as the B-H curves shown in Fig. 2. At zero, the material is not magnetized, and as we increase the magnetizing force, the flux density increases. Now suppose we increase the force only up to point 1 in Fig. 3, then we decide that we will not increase the current any further, but instead

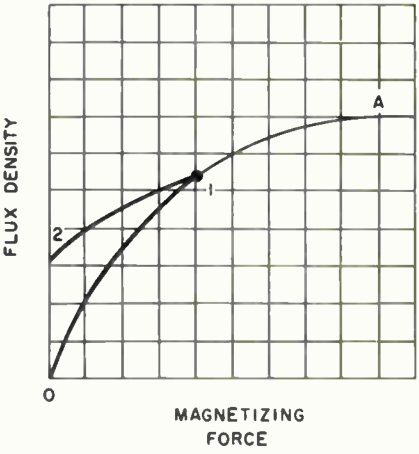


Fig. 3. Curve showing hysteresis loss in a magnetic material. If there were no loss, the curve 1-2 would coincide with the curve 0-1.

gradually decrease the current flowing through the coil, thus reducing the magnetizing force. As the magnetizing force is reduced, the flux density will decrease. However, instead of dropping back down to zero, it will follow the curve shown between points 1 and 2. At point 2, the magnetizing force has been removed entirely, but there is still a certain amount of flux. To get rid of this flux, we must actually reverse the current flowing through the coil. The power that must be applied to bring the flux density back to zero represents a loss due to the inertia of the magnetic circuit. This loss is called the hysteresis loss, pronounced hiss-ter-E-sis.

Any iron-core device operated from ac will waste part of the power applied to it in this way. There is no way that we can eliminate the hysteresis loss altogether, but the amount of power lost will depend upon the material used. By the proper choices of material, the loss can be kept to a minimum. For example, hard steel retains its magnetism and therefore the hysteresis loss in a material of this type would be quite high. On the other hand, soft iron and silicon steel retain very little of the magnetism so the hysteresis loss in the material of this type is much less than in hard steel. For this reason, the iron cores used in most transformers and chokes are made of silicon steel.

Eddy Current Losses.

Another loss that occurs in all iron-core devices is known as eddy current loss.

You will remember that when a varying current flows through a coil, a varying flux is produced in the coil. This flux will cut the turns of the coil and induce a voltage in it. The flux also cuts the turns of any nearby coil and induces a voltage in it, and if the circuit to this coil is complete, this induced voltage will cause a current to flow through it. If a transformer is made like the one shown in Fig. 4A, there are actually many paths in the core. Each path acts like a single-turn coil. We have shown two of these paths where a voltage can be induced which will result in a current flowing. These currents are called eddy currents and represent a loss.

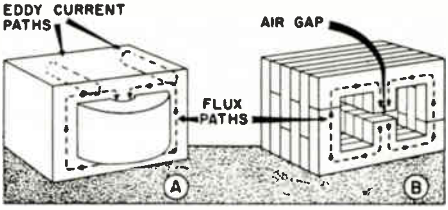


Fig. 4. If the core of a transformer is solid as at A, there are many eddy current paths in it; these can be reduced by making a laminated core as at B.

The eddy current loss in a transformer core can be kept at a minimum by making the core out of thin sheets of magnetic material called laminations. The sheets are insulated from each other by a coating of shellac or some other non-conductive material. The sheets are then stacked as shown in Fig. 4B.

Eddy current losses cannot be completely eliminated because even though the core is made of thin sheets, there are still some complete paths present that act like single shorted turns. However, making the core of thin laminations reduces the eddy current losses to a low value.

Both eddy current losses and hysteresis losses vary with the frequency. If the frequency is increased, both losses increase. Thus, although these losses do present some problem at power-line frequencies, they present an even greater problem at audio frequencies, which may extend as high as 15,000 cycles or more. These losses also explain why even laminated iron-core transformers are of no value at radio frequencies. The losses become so high that all of the energy put into the primary of the transformer would be converted into heat due to the eddy current and hysteresis losses. At radio frequencies, magnetic cores are made of finely ground powdered iron mixed with a binder to hold the particles together and insulate them from each other.

Flux Leakage Losses.

Unfortunately not all the flux produced by the magnetomotive force applied to a magnetic circuit will flow through the iron core of a device such as a transformer. Part of the flux will escape and travel through the air surrounding the core. This flux serves no useful purpose since it leaks out of the core and these flux lines do not cut the turns of the secondary winding. This loss is referred to as flux leakage loss.

In a device such as a transformer, if the magnetic material used in the core approaches the saturation point, the flux leakage losses become quite high. Therefore, to keep this type of loss as low as possible, transformers are usually designed to operate well below the saturation point. However, even then it is impossible to eliminate this loss completely, because a certain amount of the flux produced by the primary will travel in a path other than through the core.

Flux leakage is important not only because it represents a loss in the transformer, but also because the escaping flux lines may cut through some nearby part and induce a voltage in it. Thus energy in the transformer can be unintentionally fed into some other part. The amount of energy fed back may be high enough to upset the performance of the equipment.

Flux leakage can also present a problem in television receivers. Flux leaking from a transformer can deflect the electron beam in a picture tube and cause distortion in the picture. In color TV receivers flux leakage can actually cause the color picture to break up into three separate pictures of different colors or cause color fringing where objects are outlined in one or more colors.

In designing electronic equipment using transformers, engineers must consider the possibility of these undesired effects and try to keep transformer leakage fields away from the picture tube in TV receivers or other parts in the electronic equipment that could pick up interference from the field. In equipment where several transformers are used, they try to place the transformers so that there will be a minimum of interaction between them.

SUMMARY

In this section, you reviewed the facts you previously learned about magnetic circuits. You also learned some new terms. A unit of magnetomotive force that you will encounter is the gilbert and a unit of flux is the maxwell. You learned that the magnetomotive force is the force supplied throughout the entire magnetic circuit. Sometimes the force is expressed in terms of the magnetomotive force per unit length and is called the magnetizing force.

The amount of flux produced is sometimes expressed in terms of so many lines of maxwells for a given area. If the unit of cross-section area used is the centimeter, and you have 1 maxwell per square centimeter, we say the flux density is 1 gauss.

It is important for you to remember that a magnetic material can be saturated and that when the saturation point is reached, increasing the magnetomotive force will result in no further increase in flux.

The losses encountered in iron cores are important. The three most important losses are hysteresis loss, eddy current loss, and flux leakage loss. All these losses represent some energy that is being put into the primary of the transformer for which we get nothing out of the secondary. In the next section we will study transformers and you'll see the importance of these losses.

SELF-TEST QUESTIONS

(a) What is the gilbert?
(b) What is the unit of magnetic flux?
(c) What is meant by flux density?
(d) If the cross section area of a magnet is ten square centimeters and the flux density is ten gausses, what will the total number of flux lines flowing be?
(e) What is meant by magnetic saturation?
(f) Is magnetic saturation a desirable condition?
(g) How strong a magnetomotive force is required to produce saturation in air?
(h) What is a hysteresis loss?
(i) What are eddy current losses?
(j) How are hysteresis losses kept at a minimum?
(k) How are eddy current losses kept to a minimum?
(l) What are flux leakage losses?

Iron-Core Power Transformers

The ability of a varying magnetic field to induce a voltage in any conductor with which it links makes it possible to transfer power from one circuit to another without direct wiring connections. The device used for this purpose is called a transformer. In its simplest form a transformer is nothing other than two separate coils of wire wound on a common core or wound in such a way that the coils of wire are placed near each other so that the magnetic lines produced by one will cut the other.

A power transformer is wound on an iron-core. The iron-core is usually shaped like the core shown in Fig. 5A. The coils are wound on the center leg of the core as shown in Fig. 5B, one inside the other. The schematic symbol used to identify an iron-core transformer is shown in Fig. 5C.

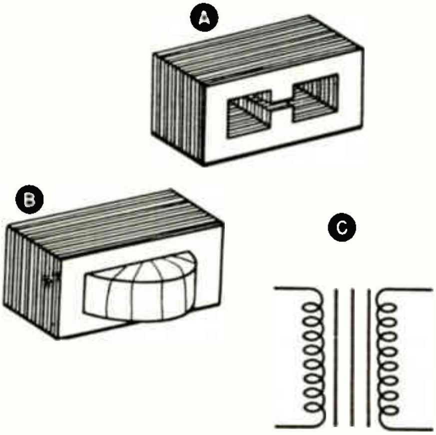


Fig. 5. The core of a power transformer is shown at A. The coils are wound on the center leg as at B. The schematic symbol for an iron-core transformer is shown at C.

Transformers are extremely important to the electronics technician, so let's learn more about them.

POWER LOSSES

In the preceding section of this lesson you learned about some of the losses that take place in magnetic cores. These losses, which are the hysteresis, eddy current, and flux leakage losses, are called "core" losses because they are characteristic of the magnetic core which is used in the transformer. However, there are also other losses in transformers.

The coils making up the transformer are wound of copper wire. Copper has a very low resistance, but nevertheless it does have some, so the current flowing through the copper wire will encounter opposition. This means power will be lost or used in forcing the current through the coil.

You know that the power is equal to voltage multiplied by the current; in other words:

$$P = E \times I$$

But from Ohm's Law we know that:

$$E = I \times R$$

Therefore, in the power formula we can substitute I × R for E, and get

$$P = I \times R \times I$$

which is usually written in the form

$$P = I^2R$$

The power lost as a result of current flowing through copper wire in a transformer will be equal to the current squared times the resistance of the wire. This loss is usually referred to as the "I squared R" loss.

Thus, in a transformer we have two groups of losses: the core losses and the copper losses. These losses appear in the form of heat. When a transformer is put into operation, it starts to heat up. The transformer will continue to get hotter and hotter until eventually a state of balance is reached where further heat generated by the transformer can be carried away by the air surrounding the transformer and by the metal chassis on which the transformer is mounted. When this balance is reached, the temperature of the transformer will stop rising, and the transformer will not get any hotter.

The amount of heat that a transformer can dissipate in this way depends upon its size. Since a large transformer will have a much greater air circulation and will be mounted on a larger area of the chassis, it can get rid of more heat than a small transformer. Therefore a large transformer is capable of handling a larger amount of power than a small transformer. As a matter of fact, the size of the transformer is usually a pretty good indication of the amount of power that it can handle safely. After you have worked on electronic equipment for a while, you'll learn to recognize from the size of a transformer approximately how much power it can handle.

Transformers can be overloaded if too much power is taken from them. When a transformer begins to overheat it is an indication that it is being overloaded. Usually when a transformer is overheated in this way you will notice a dark colored sealing compound or wax leaking out of the transformer, and often you can smell the varnish and insulation burning.

An overload of this type may be due to a defect in the transformer itself or it may be due to a defect somewhere in the equipment that is pulling excessive current from the transformer. If the transformer itself is defective, the trouble is usually that two or more turns of the transformer have touched each other so that a short circuit exists and current can simply flow around inside the transformer. When this happens there is nothing you can do except replace the transformer. However, if the defect is in the equipment rather than the transformer, and if you find it and eliminate the defect before operating the equipment any more, the chances are that the transformer will once again give satisfactory service.

If the transformer is operated with an overload, it will eventually get so hot that the insulation on the copper wire and on the terminal used to insulate one winding of the transformer from another will become overheated. Usually paper is used to insulate the various windings on a transformer. If this paper becomes too hot, it becomes charred so that it is no longer a good insulator, and the windings on the transformer will short together. When this happens, the transformer is no longer usable because it will draw more and more current and it will get hotter and hotter and eventually it will blow a fuse or the copper wire on one of the windings will melt so that the winding opens.

Transformers are designed to operate on a specific frequency. In other words, a transformer designed to operate on a 60-cycle power line will operate best only on a power line of that frequency. If you operate a 60-cycle power transformer on a 25-cycle power line or accidentally plug it into a dc power line, the transformer will burn out. A 60-cycle transformer cannot be operated on a 25-cycle power line. No transformer can be operated from dc. A 25-cycle transformer will operate on a 60-cycle power line, but 25-cycle transformers are much larger and much more costly to manufacture than 60-cycle transformers, and therefore it would be uneconomical to design a transformer for 25-cycle power and then use it on a 60-cycle power line.

In spite of the losses we have discussed, a transformer is one of the most efficient devices you will ever find. Large transformers such as those used by the power company achieve a very high efficiency, usually from 98% to 99%. Smaller transformers such as you will find in electronic equipment usually operate at an efficiency of somewhere between 95% and 98%. As far as the technician is concerned, this high efficiency means that in many cases you can ignore the transformer losses. You can consider the power output of the transformer as being equal to the power input; the difference will be only a small percent of the total power, and in evaluating the performance of the transformer, very little error will be introduced.

TURNS RATIO

The turns ratio of a transformer is the ratio of the number of turns on one winding of the transformer to the number of turns on the other winding. For convenience we usually identify the two windings on a transformer as the primary winding and the secondary winding or, more simply, as the primary and the secondary. The primary is the winding to which we apply the input power. The secondary winding is the winding from which we take power. If the primary winding of the transformer has 500 turns, and the secondary winding has 100 turns, we say that the transformer has a turns ratio of 5 to 1. This is often written 5:1. If the primary of the transformer has 100 turns, and the secondary 500 turns, then we say that the transformer has a turns ratio of 1 to 5 (1:5).

The ratio of the secondary voltage to the primary voltage will depend upon the turns ratio. If the secondary winding has five times as many turns as the primary, we can expect to get five times the voltage from the secondary that we put into the primary. Similarly, if the secondary has only half as many turns as the primary, then we can expect to get half the voltage across the secondary that we put into the primary. If we get more voltage out of the secondary than we put into the primary, the transformer is called a "step-up" transformer, and if we get a lower voltage out of the secondary than we put into the primary, then the transformer is called a "step-down" transformer.

In expressing the turns ratio of a transformer, manufacturers and technicians do not always give it as the ratio of the primary turns to the secondary turns. If a transformer has 100 turns on the primary and 200 turns on the secondary, the turns ratio is 1:2. However, sometimes this turns ratio is given as 2:1, step-up. This tells you the transformer is a step-up transformer which means there are more turns on the secondary than on the primary and the secondary has twice as many turns as the primary.

Power Consumption.

One of the things that makes a transformer so useful is that it is basically a self-regulating device. By this we mean it takes no more power from the power line to which it is connected than is needed to supply the power demanded from the secondary. In other words, if we connect a load across the transformer secondary and this load consumes 50 watts, then the power drawn from the power line by the primary will be 50 watts. Similarly, if we connect a 100-watt load across the secondary, then the power drawn from the power line by the primary will be approximately 100 watts. The primary will draw approximately the power required in order to furnish the demands of the secondary. We say approximately, because there are losses in the transformer itself, and the primary will draw the power needed to supply the secondary power plus the power needed to supply the losses within the transformer itself.

Consider what happens when the primary of the transformer is connected across the power line, but there is no load connected across the secondary. Under these circumstances, the secondary power is zero. Therefore, the primary does not have to supply any power to the secondary, and the power it will consume for this purpose will also be zero. The only power that the primary will consume from the power line will be the power to make up the core losses and a very small copper loss. Thus, when the primary of a transformer is connected across the voltage source and there is no load connected to the secondary, the transformer draws very little power from the voltage source. Under these circumstances, the transformer is very inefficient because all the power it is consuming is being wasted. However, as we load the secondary, these losses remain almost constant and as the secondary begins to use power, the primary power increases until when the transformer is being operated at its rated power, its efficiency reaches a very high value.

Because the primary power depends upon the secondary power, the actual current that will flow through the primary of a transformer will depend upon the load connected to the secondary. Ignoring the core and copper losses, if we have a 10 to 1 step-down transformer connected across a 100-volt power line, the voltage available at the secondary will be 10 volts. The turns ratio determines the ratio of the primary to secondary voltage. The ratio of the current flowing in the primary to the current flowing in the secondary also depends on the turns ratio, but it works in the opposite way. If we connect a load across the secondary that draws a current of 1 amp, then the power taken from the secondary will be 10 volts times 1 amp, which equals 10 watts. To supply 10 watts, the primary, since the voltage across it is 100 volts, needs only 1/10 of an amp and therefore this is the current that it will draw from the power line. If we increase the load across the secondary and pull 100 watts from the secondary, then the current flowing in the secondary must be 10 amps, because with a voltage of 10 volts, it will take a current of 10 amps to supply 100 watts. Under these circumstances, the primary again will pull the power needed from the power line to supply this 100 watts. This means that the primary current will be 1 amp.

Now notice what our situation is. Here we have a step-down transformer with a 10-to-1 turns ratio. This transformer steps the voltage from 100 volts down to 10 volts. However, the current acts in the opposite way. The secondary current is higher than the primary current. The secondary current will actually be 10 times the primary current if we ignore the transformer losses. Therefore in a step-down transformer, the current is stepped up and similarly in a step-up transformer where the voltage is stepped up, the current is stepped down.

Since the current drawn from the primary will vary as the loading on the secondary of the transformer varies, this means that the impedance of the primary winding must vary. If the impedance of the primary winding remained constant, then the current flowing through the transformer primary would be constant for any given primary voltage. However, since the current does vary, then the impedance must vary. This it does, in fact, and the actual impedance of the primary depends upon the impedance connected across the secondary. This is caused by the fact that when the impedance across the secondary varies, the current as well as the power demanded from the secondary will vary. The primary current and the impedance will also vary in turn.

TYPICAL POWER TRANSFORMERS

Many pieces of electronic equipment that you will service will use power transformers. Power transformers serve a number of useful purposes. First, by using a power transformer it is possible to have available a number of different operating voltages other than the single voltage available directly from the power line. Furthermore, the power transformer isolates the equipment from the power line. This is a big advantage because one side of most power lines is grounded. If you accidentally come in contact with any grounded object and some of the circuits of the electronic equipment or the metal chassis of the equipment at the same time, it is possible to get a severe shock from electronic equipment that does not use a power transformer.

The power transformer found in modern electronic equipment has a primary winding and one or more

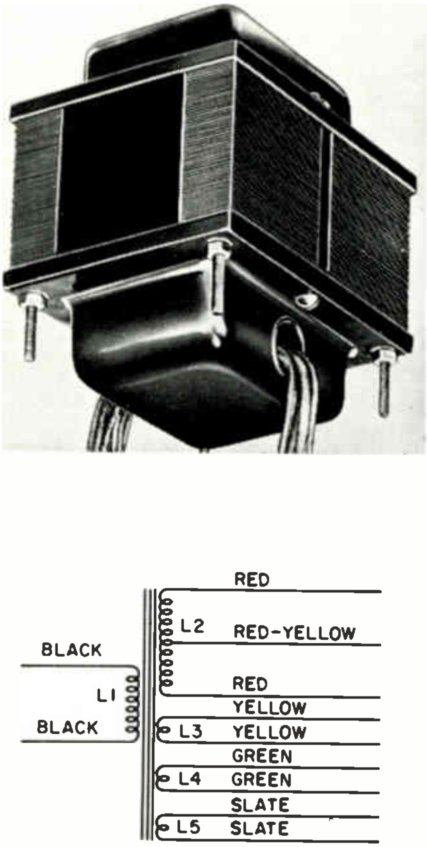


Fig. 6. A typical power transformer and its schematic symbol.

secondary windings. A photo of a typical power transformer and the schematic symbol used to represent it are shown in Fig. 6.

The winding marked L1 is the primary winding. It is usually operated from a 115-volt, ac power line.

The secondary winding marked L2 is a high-voltage secondary. Notice that this winding is center tapped. This type of winding is used with a full-wave rectifier.

A full-wave rectifier is a rectifier that rectifies both halves of each cycle. This winding is a stepup winding and is used to provide a voltage somewhat higher than that available from the power line to operate the plates of the various tubes in electronic equipment. Voltages of 250 to 350 volts are found in most circuits of modern radio and TV receivers; much higher voltages are found in transmitting equipment and in other pieces of industrial electronic equipment.

The winding marked L3 is a step-down winding. This winding is used to provide the filament voltage to operate the filament of the rectifier tube, which is used to change the ac to pulsating dc. The windings marked L4 and L5 are also low-voltage windings. These windings are used to provide the heater voltage required by the various tubes in the equipment. Some transformers have two low-voltage secondary windings like L4 and L5 on this transformer, but others have only one low-voltage secondary to heat the various tubes.

Notice that the number of turns used in the schematic symbol gives some indication of whether the windings are step-up or step-down windings. L2 has more turns than L1, and here you can expect the voltage from L2 to be higher than the primary voltage applied to L1. The windings L3, L4, and L5 have fewer turns than L1, indicating that their voltage is less than that of the primary winding. However, the schematic is not intended to show the exact number of turns or the turns ratio.

The colors have been labeled on the various leads from this transformer. This is a standard color

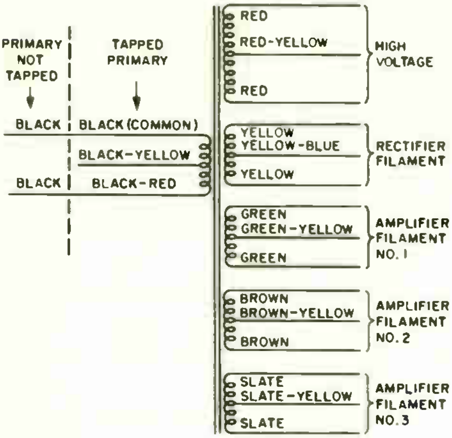


Fig. 7. The standard EIA (Electronics Industries Association) color code for power transformers.

code used to identify transformer leads. The complete color code is shown in Fig. 7. However, do not expect all transformers to follow this standard color code. Some manufacturers use a color code of their own. Therefore, even when you are using the color code to identify the leads on a transformer, you should pay some attention to how the transformer is connected into the circuit, the size of the various wires, etc., to be sure that the manufacturer has followed the standard code.

SUMMARY

We have not tried to cover all the facts about iron-core power transformers in this section of this lesson. Transformers are a subject all by themselves. Some engineers spend their whole careers designing different types of transformers. However, the information covered in this section will enable you as a technician to understand enough about transformers to know how they operate. You will learn still more about audio transformers in this lesson.

The important thing to remember from this section is that there are a number of different types of losses in transformers and that these losses cause the transformer to heat. Losses can be divided into core losses which consist of eddy current, hysteresis, and flux leakage losses, and copper losses which are called the "I squared R" losses.

Normally a transformer heats up as it is used, until it reaches a point at which it does not get any hotter. If the transformer in a piece of electronic equipment continues to get hotter and hotter and you can smell the insulation burning, it is an indication either that it is being overloaded or that there is a short either in the transformer or in the rest of the equipment.

A step-up transformer is a transformer where a higher voltage is obtained from the secondary than is put into the primary, and a step-down transformer is a transformer where a lower voltage is obtained from the secondary than is put into the primary. The power output from the secondary of a transformer is approximately equal to the power input of the primary. Thus in a step-up transformer where the secondary voltage is higher than the primary voltage, the primary current must be higher than the secondary current. Conversely, in a step-down transformer where the secondary voltage is lower than the primary voltage, the primary current will be lower than the secondary current.

Power transformers used in electronic equipment usually have several secondary windings. One secondary winding is used to provide the high voltage needed to operate the plates of the various tubes. The other secondary windings usually supply the heater voltage required by the rectifier and the other tubes in the equipment. Most transformers use a standard color code which can be used to identify the various transformer leads.

SELF-TEST QUESTIONS

(m) What is a transformer?

(n) What are the two types of losses encountered in a transformer?

(o) What happens to the power lost in a transformer?

(p) Is a transformer generally considered an efficient device?

(q) Can a power transformer designed for operation on a 60-cycle power line be used on a 25-cycle power line?

(r) What do we mean by a step-up transformer?

(s) If you have a step-down power transformer with a turns ratio of 3:1, and the current being drawn from the secondary is 3 amps, what will the primary current be?

(t) The load connected across the secondary of a power transformer consumes 230 watts. If the primary of the transformer is operated from a 115-volt power line, what will the primary current be if we consider the transformer efficiency as 100%?

(u) A power transformer has a turns ratio of 2:1. The transformer is operated from a 120-volt power line, and the device connected to the secondary winding draws a current of 4 amps. What will the primary current be?

Transformers for Specific Application

As an electronics technician, there are a number of different types of transformers that you will encounter. We are not going to try to cover all of them here, but we will discuss a few of the more common types. The material in this section of the lesson is used simply to introduce you to these special types. Later we will go into the transformers in more detail when we study the applications in which they are used.

AUDIO TRANSFORMERS

In the early days of radio, audio transformers were used as coupling devices between the various stages of the receiver. By using a step-up transformer, the strength of the audio signal could be increased in the transformer itself. This was a big help, because the tubes used in those days did not have a great deal of gain. However, modern tubes have high gain and audio transformers introduce frequency distortion, so they are no longer used with tubes for this purpose.

Impedance Matching.

You will remember that to transfer maximum power from a dc generator to a load, the load resistance must be equal to the generator resistance. In ac circuits, to transfer maximum power from a generator to a load, the load resistance must be equal to the generator impedance. To transfer maximum power from one stage in an amplifier to the following stage, the impedances must be matched. Transformers are frequently used for this purpose, particularly in transistorized equipment. For example, the output circuit of a transistor may have a much higher impedance than the input circuit of the following transistor. To transfer the power from the one transistor to the second one, an impedance-matching transformer is used.

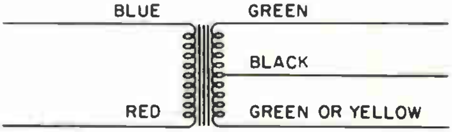


Fig. 8. An audio transformer with a tapped secondary. The colors are the standard EIA color code.

Another application in which a transformer may be used is where a single tube or transistor is used to drive two tubes or two transistors. Then an audio transformer with a tapped secondary such as shown in Fig. 8 is used. With this type of transformer, the center tap winding is either connected to ground or used to supply bias to the stage. The two tubes or transistors are driven with signals of the opposite polarity. In other words, when the signal on the top green lead in Fig. 8 is swinging positive, the signal on the lower lead that is green or yellow will be swinging negative. Thus when the current in one of the stages is increasing it will be decreasing in the other and vice versa. This type of stage is called a push-pull stage and is frequently used in the output stage of high fidelity equipment in order to obtain a high power output with low distortion. We will cover this in detail later when you study tubes and transistors.

Another place where transformers are widely used in audio circuits is in the output between the last amplifier stage and the loudspeaker. The output impedance of the power output tube or the power output transistor is generally much higher than the speaker voice coil impedance. A transformer, which is called the output transformer, is used to match the output stage to the loudspeaker in order to transfer maximum power from the output stage to the speaker. A transformer of this type will have a step-down turns ratio in order to match the higher impedance of the output stage to the lower impedance of the speaker.

You saw in an earlier lesson that to transfer maximum dc power from a generator to a load, that the generator and load resistances had to be equal. Now let's see how a transformer can be used in an ac circuit to match the load impedance to the generator impedance, so that the generator will deliver maximum power to a load that has an impedance different from the generator impedance.

In Fig. 9, we have shown how the power supplied to the load by a generator that has a no load voltage of 100 volts and an internal impedance of 50 ohms varies as different load resistors are connected across it. You will notice that when the 50-ohm load is connected across the generator, we obtain 50 watts across the load. If the load impedance is reduced below this value, then the power transferred from the generator to the load drops off.

Similarly, if the load impedance is increased above 50 ohms, the power drops off.

With a 50-ohm load connected across the generator, the total circuit resistance is 100 ohms: the 50-ohm load, plus the 50-ohm generator impedance. The 100 volts generated will be divided with 50 volts being dropped in the generator and 50 volts in the load. The current flowing in the circuit will be 1 amp.

LOAD RESISTANCE IN OHMS	POWER IN WATTS
200	32
150	37.5
100	44.4
50	50
25	44.4

Fig. 9. Power supplied by a 100-volt generator with an internal impedance of 50 ohms for various values of load resistance.

If we remove the 50-ohm load resistor, and connect some other device in its place that will draw a current of 1-amp from the generator, then there will be 50 volts across this device and the power supplied to it will be 50 watts, which we know is the maximum power that can be taken from the generator. A transformer can be used for this purpose providing it has the proper turns ratio, and providing the correct load is connected across the secondary of the transformer.

The usual problem is to have the generator and the load and then have to select the transformer. Let's assume that we have a 2-ohm load resistor we want to connect across the generator and see how a transformer can be used to get 50 watts from the generator to the load.

We know that the maximum power that can be transferred from the generator to the load is 50 watts. Now let's find out what the voltage across the resistor and the current through the resistor must be in order to get 50 watts into the resistor. Remember the formula:

$$P = I^2 \times R$$

We know that $P = 50$ watts, and $R = 2$ ohms; therefore we can find the value of I^2 in this manner:

$$I^2 = 50 + 2 = 25$$

This means that the current squared is equal to 25. We know that the square root of 25 is 5, because $5 \times 5 = 25$. Therefore the current that must flow through the resistor is 5 amps. In order to figure how much voltage we need to get a current of 5 amps to flow through a 2-ohm resistor, we use the formula: $E = I \times R$. This gives us 2×5, which equals 10 volts.

So far we have found that to get 50 watts into a 2-ohm load resistor, we must have a voltage of 10 volts across it. When we have 10 volts across the resistor, a current of 5 amperes will flow through it, and the power supplied to the resistor will be 50 watts. However, we still have the problem of getting the 10 volts across the resistor.

The transformer presents an easy method of doing this. We know that when we had maximum power transfer from the generator to the load, we had 50 volts across the load. However, in the problem we have set up, we want only 10 volts across the load. The way to satisfy both of these conditions is to connect a transformer across the generator as shown in Fig. 10. If we use a transformer with a turns ratio of 5 to 1, we will be able to satisfy these conditions.

You will remember that the transformer is a self-regulating device. The primary will take the power from the source needed to supply the power demanded by the secondary. Under these circumstances when the generator, transformer, and load are connected as shown in Fig. 10, the primary current that will flow will be 1 amp. This means that there will be 1 amp through the primary of the transformer, and therefore the power consumed by it will be 50 watts. The 50 volts applied to the primary will be stepped down by the transformer to give 10 volts across the secondary. With the 2-ohm load connected across the secondary, the secondary current will be 5 amps, and the power con-

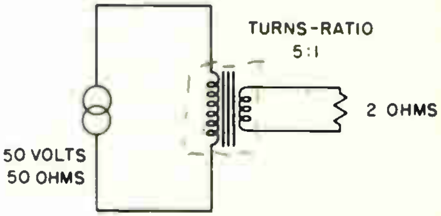


Fig. 10. A transformer used to match a 2-ohm resistor to a generator with an internal resistance of 50 ohms.

sumed by the secondary will be 50 watts. Since the transformer is a step-down transformer, the current is stepped up. The primary current of 1 amp is stepped up to a current of 5 amps in the secondary.

Under these circumstances, as far as the generator is concerned, it works exactly as it would if a 50-ohm resistor were connected across it. The transformer has matched the two-ohm resistor to the generator. Technicians say that the generator "looks into" the load and it looks like a 50-ohm load connected across it. Because the transformer matches the load impedance to the generator to provide the generator with the impedance required to transfer maximum power from the generator to the load, the transformer is called an impedance-matching transformer.

Turns Ratio.

Notice the ratio of the two impedances we matched. The generator impedance was 50 ohms, the load 2 ohms. The ratio of these two impedances is 50 to 2 or 25 to 1. The turns ratio of the transformer, however, was 5 to 1. But 5 is the square root of 25. Thus the relationship between the impedances to be matched and the turns ratio of the transformer needed to match the impedance is:

$$\frac{N1}{N2} = \sqrt{\frac{Z1}{Z2}}$$

where Z1 is the generator impedance, Z2 the load impedance, N1 the number of turns on the primary of the transformer, and N2 the number of turns on the secondary. Thus, N1/N2 is the turns ratio.

AUTOTRANSFORMERS

The schematic of another type of transformer is shown in Fig. 11. As you can see from the schematic, this transformer consists of a single winding with a tap. It is called an autotransformer because it has only one winding. (Auto is the Greek word for "self".) In the transformer shown in Fig. 11A, the secondary voltage is higher than the primary voltage because there are more turns on the secondary than there are on the primary. In the transformer shown in Fig. 11B, the secondary voltage is lower than the primary voltage because the primary has more turns than the secondary.

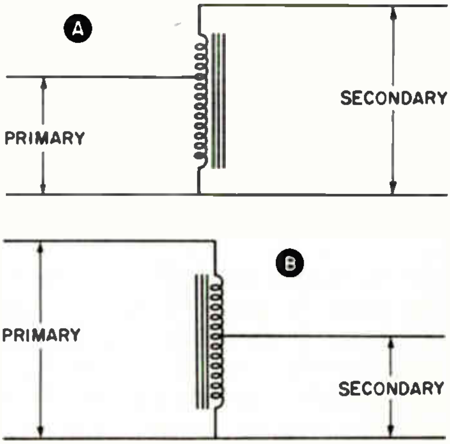


Fig. 11. Schematic of an autotransformer.

The autotransformer is different from a conventional transformer in that the primary and secondary windings are not insulated from each other. The voltage applied to the primary will set up a magnetic field, and this magnetic field will cut all the turns of the secondary, including those which may be a part of the primary, and induce a voltage in them. This voltage will appear across the secondary terminals of the transformer and if we connect a load to these terminals, current will flow through the load.

Autotransformers have the disadvantage that the primary and secondary windings are not completely isolated from each other electrically. In other words, there is an electrical connection between the primary and secondary windings. As a matter of fact, one lead connects directly to both primary and secondary windings as you can see from the diagrams in Fig. 11. However, they have the advantage over the transformer with two separate windings in that they are more economical to manufacture and therefore are frequently used in modern electronic equipment where keeping the cost as low as possible is of major importance.

RF TRANSFORMERS

Another transformer that you will encounter frequently is the rf radio frequency transformer. This type of transformer, because of the high frequencies at which it operates, is either an air-core or a powdered iron-core transformer. A typical rf transformer designed for use at standard broadcast band frequencies is shown in Fig. 12.

RF transformers are used in the stages of a radio or TV receiver that are designed to amplify the received signal frequency. In other words, in the case of a broadcast band receiver, the signal is picked up and amplified by one or more rf stages before it is processed in any way. RF transformers are used between stages of this type.

In most cases, the secondary of the transformer, at least, is used in conjunction with a variable capacitor to form a resonant circuit. The rf transformer acts very much like the step-up transformer, because if the secondary is tuned to resonance, the circuit forms a series-resonant circuit and there will be a resonant voltage step-up across the secondary of the transformer. This situation exists even though the primary of the transformer may have the same number of turns as the secondary. Here the step-up in voltage is being obtained because of the action of the resonant circuit, rather than the action of the transformer.

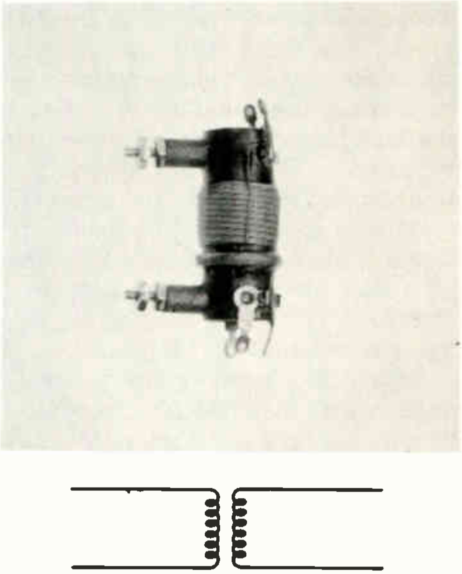


Fig. 12. A typical rf transformer and its schematic symbol.

In TV receivers where the rf stages must operate on a much higher frequency, an rf transformer may consist of only one or two turns of wire on the primary winding and the same number of turns on the secondary. If one winding of the transformer is tuned to resonance, it is usually tuned by stray circuit capacitances and capacitances in the tubes or transistors used in the stage rather than by a separate variable capacitor.

RF transformers are sometimes called rf coils, but are actually transformers. Their operation is similar to that of the iron-core transformers you studied earlier in this lesson.

I-F TRANSFORMERS

Modern radio and television receivers use what is called a superheterodyne circuit. In this type of circuit the incoming signal is fed to a stage called a mixer stage where it is mixed with a locally generated signal. The output of the mixer stage produces a new signal frequency which is called the intermediate frequency. We abbreviate this i-f and call the stages used to amplify this signal i-f stages. Between the various i-f stages we use transformers called i-f transformers.

A typical i-f transformer and its schematic diagram are illustrated in Fig. 13. The primary winding of the transformer and its capacitor form a parallel-resonant circuit, and the secondary winding and its capacitor form a series-resonant circuit. Both the primary and the secondary windings are tuned to the same frequency and usually the two windings have exactly the same number of turns on them. However, again because the secondary is a series-resonant circuit, there is a resonant voltage step-up and the voltage across the secondary winding will be higher than the voltage across the primary winding.

Even though the primary and secondary windings of an i-f transformer are tuned to resonance at a specific frequency, they are designed so that they have a certain bandwidth. By this we mean that instead of passing only one specific frequency, the transformer will pass a band of frequencies. The actual bandwidth depends upon the design of the transformer and the frequency at which it operates. The bandwidth of a transformer can be shown by means of a response curve such as shown in Fig. 14. Here you will see that the resonant frequency is 455 kc, but there is very little differ-

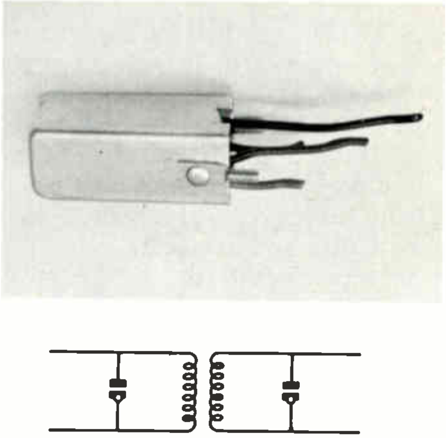


Fig. 13. A typical i-f transformer and the schematic symbol for it.

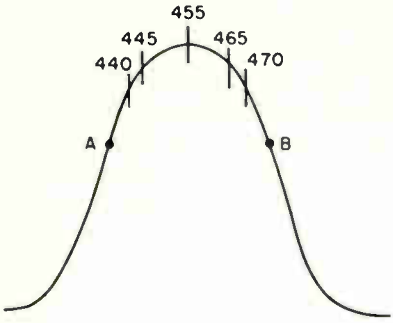


Fig. 14. An i-f transformer response curve.

ence in the response of the transformer either 10 kc below or 10 kc above this frequency. Under these circumstances, the transformer would have a bandwidth of at least 20 kc. In other words, it will pass signals having a frequency from 445 kc to 465 kc satisfactorily.

As a matter of fact, we can go a little further down the curve and see that there is not too much difference between 440 kc and 455 kc. You can see that deciding the bandwidth is a rather arbitrary thing. Engineers have set up as a standard the point where the response falls to .707 of the response at the resonant frequency. This is the half-power point you have already studied. The bandwidth of the i-f coil is the frequency between the .707 point on the low side of the curve and the .707 point on the high frequency side of the curve. These points have been marked A and B on the response curve shown in Fig. 14.

They are called the "3-db down" points. The abbreviation "db" means decibel. It is a means of expressing power ratio. The 3-db down points, A and B in Fig. 14, are within 3-db of the resonant frequency.

We do not expect you to understand the decibel at this time; we will go into it in more detail eventually. However, keep in mind the expression "3-db down", because this expression is frequently used by technicians and engineers. It is an idea that is somewhat difficult to grasp, but one of the first steps in seeing what is meant is becoming familiar with the term. Now that you have been introduced to it, the next time you will see it, it will not seem quite so strange to you.

When you look at Fig. 13 you might think that the primary and secondary windings are placed so far apart that there would be very little coupling between the two of them. However, there actually is considerable coupling between the two windings. The spacing of the transformer windings is adjusted to give exactly the desired amount of coupling. If the coils are placed too close together, then the curve shown in Fig. 14 tends to flatten out and have a dip in the center around a 455 kc point.

In TV i-f transformers, the coils are placed much closer together; in fact, often one is wound directly on top of the other. This is done in order to provide what is called very tight coupling and to spread out the response curve to pass a wide band of frequencies. You will see later that in television we must be able to pass a wide band of frequencies; otherwise, part of the picture information in black and white transmissions or part of the color information in color broadcasts will be lost.

TV i-f transformers do not have

a separate capacitor across the primary and secondary windings like the one shown in Fig. 13. There is enough capacity in the circuit and in the output and input in the various stages to provide the capacity required in order to bring the windings on the transformer to resonance.

SUMMARY

In this section of the lesson, you have been introduced to a number of new types of transformers.

You have learned that transformers are used between the audio stages in some pieces of equipment. Many of these transformers are step-up transformers so that the voltage across the secondary may be two or three times the voltage across the primary. However, in some high-power audio equipment, step-down transformers are used between audio stages. Transformers with tapped secondaries may be used when one tube must drive two tubes.

Transformers are used as impedance-matching devices. In order to get maximum power from a generator to a load, the load impedance must be equal to the generator impedance. This situation can be met by using a transformer with a suitable turns ratio to match the load impedance to the generator impedance so that the generator operates as if it were working into a load equal to its own internal impedance. Impedance-matching transformers are used between the output stage of a radio or TV receiver and the loudspeaker. Because these transformers are used at the output of the receiver they are usually called "output" transformers.

You have learned that the autotransformer is a single-winding transformer. Part of the transformer winding serves as both the primary and secondary. The autotransformer is frequently used to step up the line voltage if it is somewhat lower than normal.

We have also mentioned rf transformers. Although we did not go into a great deal of detail about them, you should recognize an rf transformer the next time you see one. An rf transformer has two windings, a primary and a secondary winding, and it operates in very much the same way as an iron-core transformer.

I-F transformers have both a tuned primary and a tuned secondary. The primary is a parallel-resonant circuit. The secondary is a series-resonant circuit. An i-f transformer has a certain bandwidth; this means that the transformer will pass frequencies above and below the frequency to which it is resonant. The bandwidth of a transformer is defined as the frequency difference between a point on the low side of the response curve and a point on the high side of the response curve at which the output from the transformer is .707 of the output at resonance. These points are called "3-db down" points.

SELF-TEST QUESTIONS

(v) Are step-up type audio transformers used in modern electronic equipment?

(w) What is the major use of audio transformers in electronic equipment?

(x) Why is it important that the

output stage in a radio receiver or a TV receiver be matched to the speaker voice coil?

(y) What type of audio transformer is used to drive a push-pull stage from a single driver stage?

(z) What must the turns ratio of an output transformer be to match a speaker with a 10-ohm voice coil to an output stage that has an output impedance of 1000 ohms?

(aa) What is an autotransformer?

(ab) Is an autotransformer a step-up transformer or is it a step-down transformer?

(ac) What is the disadvantage of an autotransformer?

(ad) What is an rf transformer?

(ae) What type of core would you expect to find in an rf transformer?

(af) In a typical i-f transformer used in a broadcast receiver, the primary and secondary windings will have the same number of turns. However, in spite of this, the voltage across the secondary winding will be higher than the voltage across the primary winding of the transformer. Why is this so?

Iron-Core Chokes

A choke is a coil used to purposely introduce a high reactance in a circuit. An iron-core choke is a coil wound on an iron core. A typical iron-core choke and the schematic symbol used to represent it are shown in Fig. 15.

Iron-core chokes are sometimes found in audio equipment, but their most important use is in power supplies. Here they are used in conjunction with capacitors to smooth the pulsating dc from the output of the rectifier. Chokes that are used for this purpose are called filter chokes or smoothing chokes.

PHYSICAL AND ELECTRICAL CHARACTERISTICS

It is sometimes difficult to distinguish an iron-core choke from a small power transformer. However, an iron-core choke usually has only two leads, whereas a power transformer has more than two leads. However, some iron-core chokes have a tapped winding. This type of choke has three leads and is very rare; most chokes have only two leads and can be distinguished easily from a transformer by this characteristic.

The core on which an iron-core choke is wound is similar to a transformer core. Thin sheets of laminated silicon steel are used in constructing the core. A frame is generally provided around the core and this frame serves the dual purpose of holding the laminations of the core together tightly and also in providing a convenient method of mounting the choke. You can see the frame in Fig. 15.

The core of an iron-core choke is made of silicon steel, which keeps the hysteresis losses in the choke as low as possible. The core is laminated to keep the eddy current losses low. The pulsating dc that is fed to a filter choke is actually a mixture of ac and dc. The ac has exactly the same effect in the choke as it has in a transformer, so both hysteresis and eddy current losses are present.

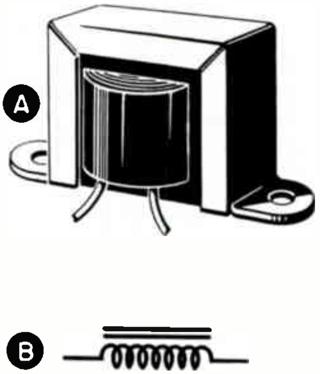


Fig. 15. A typical iron-core choke and its schematic symbol.

A choke used in a power supply usually has a fairly high inductance. Inductances from about 1 henry up to 30 or 40 henrys are quite common.

The size of wire chosen for winding a choke is determined by the current that will flow through the choke.

When an iron-core choke is used as the filter choke in the power supply, there is usually a high dc current flowing through it; superimposed on this dc is ac. The wire with which the choke coil is wound must be large enough to accommodate this current without overheating.

The current that flows through the choke coil will govern the size of core required. Saturation, which you have already studied, must be avoided in chokes. It can be avoided only by using an iron-core large enough to handle the magnetic field developed by the coil without reaching the saturation point.

If a choke becomes saturated, its inductance drops. This in turn results in a decrease in the inductive reactance and hence a decrease in its effectiveness in filtering the pulsating dc to pure dc.

In your career as an electronics technician, you will have occasion to replace defective filter chokes. When selecting a replacement, keep in mind that if you use too small a choke, it can be saturated and thus be very ineffective as a filter. Therefore, the replacement choke should be of approximately the same physical size as the original choke and the wire used to wind the choke should be at least as large as the wire used to wind the original choke. Technicians usually do not concern themselves with the wire size because manufacturers rate their chokes giving the inductance and the current that the choke is designed to handle. Thus, a choke rated at 8 henrys, 250-ma, is a choke that will have an inductance of 8 henrys when a dc current of 250 milliamperes is flowing through it. If the current flowing through the choke is higher than 250 milliamperes, the core will approach the saturation point, and the inductance will drop. If the current flowing through the choke is less than 250 milliamperes, the inductance of the choke will be somewhat higher than 8 henrys. This will not cause any trouble; the equipment will work as well as ever. If the current flowing through the choke exceeds the 250-ma current rating substantially, the chances are that the choke will overheat and may eventually get so hot that it will burn out.

HOW CHOKES ARE USED

We mentioned that chokes are used along with capacitors in power supplies to help smooth the pulsating dc at the output of the rectifier to pure dc at the output of the filter network. A typical circuit showing how a choke and a capacitor may be used is shown in Fig. 16. To see how the combination acts to filter the pulsating dc, first consider that the pulsating dc at the input actually consists of two components, ac superimposed on dc. To understand the action of the choke and capacitor, we can study their action on the two components separately.

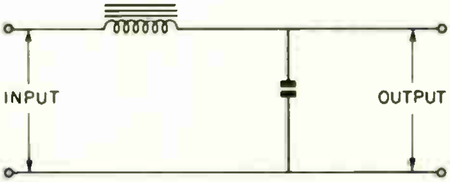


Fig. 16. A filter network made up of a choke and a capacitor.

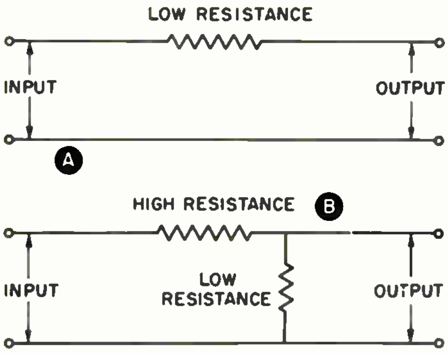


Fig. 17. The effect of the filter circuit for a dc component is shown at A, and for an ac component at B.

You know that a choke offers little or no opposition to the flow of dc through it. The only opposition the choke will offer to the flow of dc will be due to the resistance of the wire used to wind the coil. Since this is normally quite low, the dc can flow from the input through the choke coil to the output without any difficulty. The capacitor is charged by the dc, but once it is charged, it will not draw additional dc through the choke. Between the input and output circuits, we actually have a very simple circuit like the one shown in Fig. 17A insofar as the dc is concerned. Notice that we have only a low resistance in the circuit. The capacitor is not shown, and it can be completely ignored insofar as the dc flowing in the circuit is concerned.

The action of the choke and capacitor to the ac component is completely different. The choke, since it has inductance, has inductive reactance and is usually selected so that the inductive reactance will be quite high. The capacitor on the other hand is selected with a low capacitive reactance. Thus, insofar as the ac is concerned, we have a circuit like the one shown in Fig. 17B. Here we have a high resistance taking the place of the choke and a low resistance taking the place of the capacitor. Now these two "resistors" act like a voltage divider and most of the voltage will be dropped across the high resistance and very little will appear across the low resistance in the output. If the reactance of the choke is ten times the reactance of the capacitor, the ac component at the output would be approximately 1/10 the ac at the input.

If further filtering is needed to smooth the pulsating dc more than it can be smoothed by a single choke and capacitor, two chokes and two capacitors can be used as shown in Fig. 18. Here, if there is a 10-to-1 reduction of hum (which is what the ac is called since it produces hum in the output of the device) in each section, the total hum reduction in a two-stage filter network of the type shown in Fig. 18 would be 100. This means that if a 100-volt ac signal is applied to the input of the circuit, there will be a 1-volt ac signal at the output. On the other hand, dc applied to the input would flow through the filter network relatively unhampered.

In a two-stage filter network such as shown in Fig. 18, the first choke, marked L1, is called the input filter choke and the second one, marked

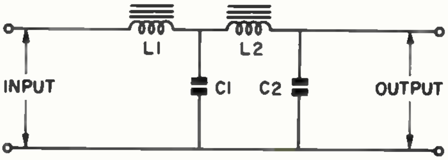


Fig. 18. A two-stage filter network.

L2, is the output filter choke. The choke, L1, is sometimes a special type of choke called a swinging choke. This type of choke is made with a rather small air gap in the core. The core is somewhat smaller than it should be for the amount of current that will flow through the choke so that it saturates rather easily and its inductance varies. The advantage of using this type of choke is that we are able to obtain better voltage regulation at the output of the power supply. By voltage regulation we mean keeping the output voltage more nearly constant as the load or current taken from the power supply vary. The second choke, marked L2, is usually called a "smoothing" choke.

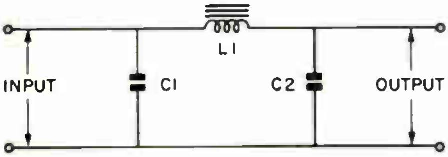


Fig. 19. A capacitor input filter.

Another type of filter network is shown in Fig. 19. This type of filter is often called a brute force filter. Notice that this network uses two capacitors and one choke. This type of network is called a capacitor input filter, whereas the one shown in Fig. 18 is called a choke input filter. In Fig. 19, C1 is called the input capacitor and C2 the output capacitor. The dc output voltage obtained from a capacitor input type of filter is somewhat higher than can be obtained from a choke input filter, but the voltage regulation is better with a choke input filter. Both types are found in modern electronic equipment.

SUMMARY

Chokes are important to the electronics technician, because he will encounter them in most pieces of electronic equipment that he is called upon to service.

Most chokes look like iron-core transformers except that they have only two leads, whereas a transformer has at least three and usually more leads. The cores of chokes are made of laminated sheets of silicon steel. This type of construction is used to keep the eddy current and hysteresis losses low.

Chokes can be saturated if the current passing through them is too high. Therefore, in replacing a defective choke in a piece of electronic equipment, the technician should use a replacement at least as large as the original. Filter chokes are used in conjunction with capacitors to smooth the pulsating dc at the output of a rectifier to pure dc at the output of the filter circuit. Chokes are used for this purpose because they offer a low-resistance path to the flow of dc through them but offer a high reactance to the flow of ac through them. The pulsating dc at the output of the rectifier actually consists of a dc component with an ac component super-imposed on it. The choke lets the dc component go through with little or no effect on it, and in conjunction with the capacitor greatly reduces the ac component.

SELF-TEST QUESTIONS

(ag) How can you tell a filter choke from a power transformer?

(ah) What is the purpose of the filter choke in a power supply?

(ai) What is the danger of passing too high a current through a filter choke?

(aj) Does a filter choke offer a high resistance or does it offer a low resistance to the flow of dc through it?

(ak) In a two-stage filter network, what are the names given to the two filter chokes?

(al) What is a swinging choke?

Relays

Another magnetic device is the relay. Although relays are used chiefly in transmitters and industrial equipment, they are found in some radio and TV receivers with automatic tuning systems. Relays are used to open and close circuits electrically. They are electric switches. In many ways a relay is similar to a mechanical switch. In order to understand relays, you should understand mechanical switches. So let's look at them first.

SWITCHES

Switches are made with several different contact arrangements. The simplest switch is one that has two positions. In one position, the circuit is open; in the other position the circuit is closed. This is called a single-pole, single-throw switch, abbreviated SPST. Fig. 20 shows an example of this kind of switch. In the position shown at A, the circuit is closed. When the blade is raised as at B, the circuit is open.

The switch illustrated in Fig. 20 is only one kind of SPST switch. They are made with different types of contact arrangements. However, although the mechanisms are different, the electrical principles are the same--in one position of the switch the circuit is open, and in the other position the circuit is closed. An ordinary light switch such as you have in your home is another example of an SPST switch.

Another type of switch, called a single-pole, double-throw switch (SPDT) is arranged so that in one

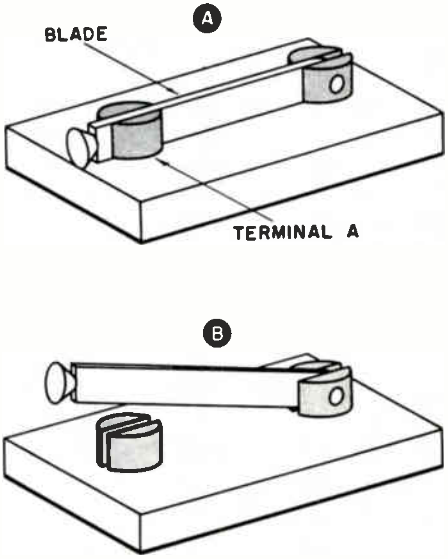


Fig. 20. A single-pole, single-throw switch is shown closed at A, and open at B.

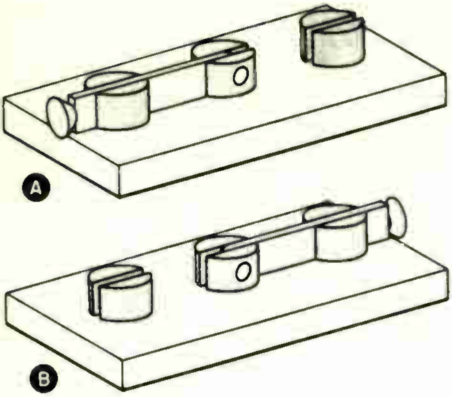


Fig. 21. A single-pole, double-throw switch makes contact in either of the two positions shown at A and B.

position it closes one circuit, and in the other position it closes another circuit. Fig. 21 shows an example of this type of switch.

A double-pole, single-throw (DPST) switch shown in Fig. 22 is really two switches in one. It has two blades, mechanically joined, so they are thrown open or closed at the same time. As in the SPST switch, when the blades are down, the circuits are closed, and when they are up, the circuits are open.

The double-pole, double-throw (DPDT) switch shown in Fig. 23 has two blades joined mechanically and two closed positions. There are also triple-pole, single-throw (TPST) switches, and triple-pole, double-throw (TPDT) switches.

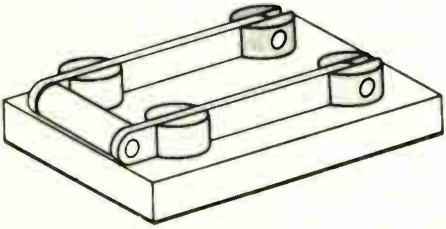


Fig. 22. A double-pole, single-throw switch.

Relays are also made with all these different types of contacts. Let's see how a relay works.

SIMPLE RELAY CONSTRUCTION

In its simplest form, a relay consists of nothing other than an iron-core coil such as shown in Fig. 24 with a bar of magnetic material placed on a pivot near one end of the core. One end of the bar is attached to a spring. The tension of the spring lifts the bar up and away from the core of the magnet. The motion of the top of the bar is usually restricted by some non-magnetic material so that when the relay is not energized, the bar will assume the position shown in Fig. 24A.

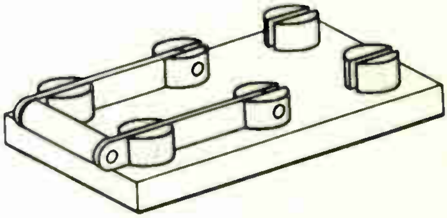


Fig. 23. A double-pole, double-throw switch.

When a voltage is applied to the relay coil, current flows through the coil and the magnetic field produced attracts the bar on top of the coil and pulls it down as shown in Fig.

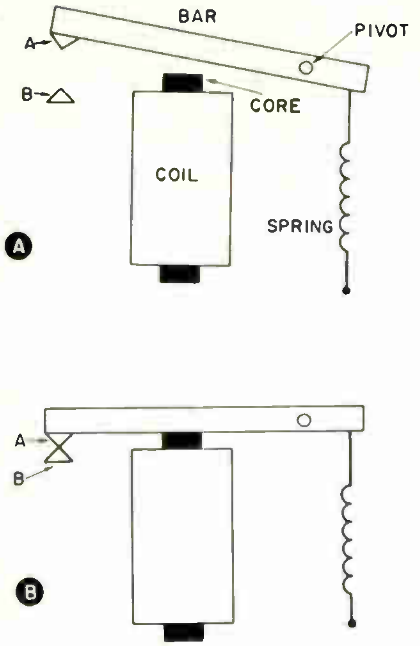


Fig. 24. Basic operation of a relay.

24B so that the contacts A and B are closed. Leads can be connected to terminals A and B so that energizing the relay closes the circuit and current will flow through the circuit.

Some relays operate from dc, but others are made that operate from ac. There is usually not too much difference between small ac and small dc relays, except that the spacing between the bar and the magnet is usually somewhat greater in an ac relay. If the bar comes too close to the magnet in an ac relay, there may be some tendency for the relay to chatter. By chatter, we mean that the bar moves up and down as the ac goes through its cycle and the strength of the magnet varies. If the bar is made of heavy enough material and kept a reasonable distance from the magnet, this problem is usually not encountered in small ac relays.

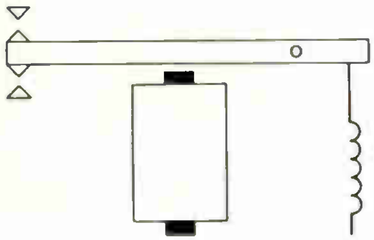


Fig. 25. A single-pole, double-throw relay.

RELAY CONTACTS

The contacts on relays are identified using the same system that is used to identify the contacts on an ordinary switch. The movable arm of a relay or switch may be made to make contact in one position and no contact in the other position, or it may be made to make contact in either of two positions.

If there is only one set of contacts on a relay, we call it a single-pole, single-throw relay. The relay shown in Fig. 24 has this type of contact.

Single-pole, double-throw relays are arranged so that when the coil is energized, it pulls the bar down and the bar makes contact with one terminal and when the coil is not energized, then the bar moves up under the tension of the spring and makes contact with another terminal, as shown in Fig. 25.

Relays are also made with all the other contact arrangements that we

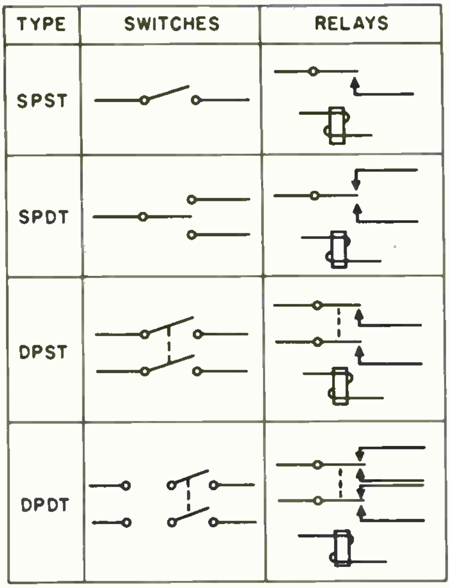


Fig. 26. Schematic symbols for different types of switches and relays.

showed for mechanical switches. Fig. 26 shows the schematic symbols for different types of switches and relays.

SPECIAL PURPOSE RELAYS

There are many special types of relays designed for specific jobs.

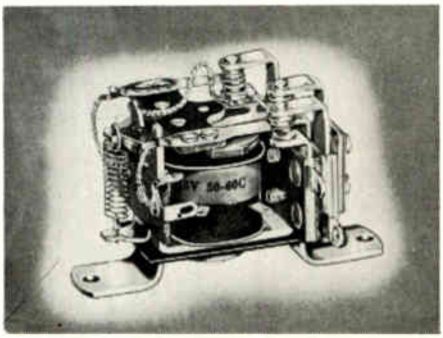
Time-Delay Relay.

One type of relay is a time-delay relay. In this type of relay, the contacts do not close until a predetermined time has elapsed after the power is applied to the relay. After this time has elapsed, the contacts are closed and the circuit is complete. Time-delay relays are usually either SPST or DPST relays. Double-throw time-delay relays are seldom used. Time-delay relays are often used in transmitting equipment where it is desirable to allow the cathode of the tubes to warm up before the other operating voltages are applied.

Overload Relay.

Another type of relay is used for protective purposes in electronic equipment. This type of relay is often called an overload relay. It is designed so that the relay is energized and the circuit opens when the current exceeds a predetermined value. Sometimes a break-down in one circuit will affect another. The current in the second circuit might rise so high that some valuable part such as a tube would be destroyed. With an overload relay in the circuit, when the current rises above a safe value, the relay automatically opens, removing the voltage from the tube, thus saving it from destruction.

As you might expect there are some circuits in which if the current drops below a predetermined value, some damage might result or the equipment might fail to operate



A relay of the type found in electronic equipment. This is a triple-pole, double-throw type.

Fig. 27. A thermal type overload device.

properly. There are relays that are set to open when the current drops below a predetermined value.

Another type of overload device that is widely used in TV receivers is shown in Fig. 27. This type of overload is not a relay, but instead is made of a metal strip which is made from two dissimilar metals. The current flowing through the strip causes the metals to heat and they expand at different rates. If the metal gets hot enough, the expansion will be great enough to distort the metal so that it springs loose from the contact holding it in place and this opens the circuit. You will run into this type of overload device frequently in TV receivers. Be sure not to confuse it with an overload relay. It serves the same basic purpose, but it is a thermal overload device rather than a magnetic relay overload device.

SUMMARY

Relays are devices used to close circuits automatically, to protect circuits either by waiting for a predetermined time before closing the circuit or by opening the circuit when an overload occurs. The relay consists of an electromagnet, a bar which can be held in one position by the magnet and returned to the other position by the spring, and one or more sets of contacts.

Relays are found in many different types of electronic equipment. About the only types of defects you are likely to encounter in relays are open coils, and burned or dirty contacts. Sometimes replacement coils are available, sometimes the contacts can be cleaned, but with some types of relays the only suitable remedy for a defect is to replace the entire relay.

SELF-TEST QUESTIONS

(am) What do we mean when we refer to a switch as an SPST switch?

(an) What is meant by SPDT?

(ao) What do the letters DPDT mean?

(ap) What causes the contacts in a relay to close?

(aq) What is a time-delay relay?

(ar) What is an overload relay?

(as) Overload protective devices are frequently found in TV receivers - are these overload devices overload relays?

LOOKING AHEAD

The iron-core devices that you studied in this lesson are all devices that will be found frequently in electronic equipment. Of the three, transformers and chokes will be found in more different types of equipment than relays, but there are many pieces of equipment that use a large number of relays. Defective transformers, chokes, and relay coils can frequently be recognized by a characteristic odor that they give off when they have been overheated. Also, you will generally notice signs of sealing wax and other compounds leaking from an overheated iron-core device. The insulation becomes brittle and can often be crumbled with your fingers. You will not go far in your electronics career before you run into one of these devices that has broken down. Usually it is a simple matter to locate and replace one of these parts that is defective.

In the lessons you have so far studied, you have covered a number of the basic components found in electronic equipment. Now, you are ready to study vacuum tubes, and then see how the components are used with vacuum tubes in amplifiers and other interesting circuits.

ANSWERS TO SELF-TEST QUESTIONS

(a) The gilbert is a unit of magnetomotive force. The gilbert is slightly smaller than the ampere-turn. The gilbert is particularly useful in expressing the magnetomotive force of a permanent magnet.

(b) The maxwell is the unit of magnetic flux. One line of flux is equal to one maxwell.

(c) The flux density is a measure of the number of flux lines passing through a given area. A flux density of one line or one maxwell per square centimeter is known as a gauss.

(d) 100 maxwells or lines. To find the total number of lines you multiply the area in centimeters by the flux density; in this case 10 × 10 = 100 lines.

(e) When magnetic saturation occurs, all of the molecules in the core material are aligned with their north poles pointing in one direction and their south poles pointing in the other so that any further increase in magnetomotive force cannot produce any further alignment of the molecules or any increase in flux.

(f) No - in fact it produces a number of undesirable effects and should be avoided.

(g) Magnetic saturation cannot be produced in air regardless of how strong the magnetomotive force is.

(h) A hysteresis loss is a loss due to the inertia of a magnetic circuit. When the core in a choke or transformer is magnetized by passing a current through the coil, the core does not return to a state of zero magnetism when the current is removed. Some magnetism will remain and power must be used to bring the flux density back to zero. This power required to bring the flux density back to zero represents the hysteresis loss.

(i) Eddy current losses are losses due to the fact that a core of the transformer choke acts like a complete turn of a coil and the flux cutting this turn induces a voltage in it which causes a current to flow. This represents a loss which is known as an eddy current loss.

(j) By selecting a material that has very little magnetic inertia. Materials such as silicon steel have much lower hysteresis loss than hard steel.

(k) Eddy current losses are kept at a minimum by making the core of a transformer or choke coil in the form of sheets of metal rather than a solid piece. The sheets are electrically insulated from each other so that the flow of eddy currents across the entire core material is prevented.

(l) Flux leakage losses are due to the fact that part of the flux escapes from the core and travels through the air surrounding the core. This flux serves no useful purpose since the flux lines in the case of a transformer would not cut the secondary winding of the transformer.

(m) In its simplest form a transformer is two separate coils of wire wound on a common core and placed near each other so that the magnetic lines produced by one coil will cut the other coil.

(n) The two types of losses encountered in a transformer are core losses and copper losses.

(o) The power lost in a transformer is turned into heat. The heat is radiated by the transformer and the chassis on which the transformer is mounted.

(p) Yes. A transformer is one of the most efficient devices you will encounter in electronics. Large power transformers may have efficiencies as high as 98% or better. This means that 98% of the power taken by the primary winding of the transformer is available for useful work at the secondary winding of the transformer.

(q) No. A transformer designed for 60-cycle operation will overheat and burn out if it is operated on a 25-cycle power line.

(r) A step-up transformer is a transformer that has more turns on the secondary winding than on the primary winding. As a result, the voltage available across the output of the secondary winding will be higher than the voltage supplied to the primary winding. The ratio by which the voltage is stepped up is determined by the ratio of the number of turns on each winding of the transformer. In other words, if the secondary winding has twice as many turns as the primary winding, the voltage available across the secondary will be twice the voltage applied to the primary.

(s) 1 amp. A step-down transformer steps the voltage down by the turns ratio; however, it steps the current up by the same turns ratio. Therefore, if the secondary current is 3 amps, the primary current will be only 1 amp.

(t) 2 amps. To find the current we divide the power by the voltage; in this case we have 230 watts divided by 115 volts equals 2 amps. The efficiency of a transformer is usually so high that we can ignore any losses and if the power consumed by the secondary is 230 watts, we can consider that the primary power will also be 230 watts.

(u) If the turns ratio of a transformer is 2:1, and the transformer is operated on a 120-volt power line, then the secondary voltage must be 60 volts. Since the current drawn by the secondary winding is 4 amps, then the power the secondary winding is supplying is 60 × 4 = 240 watts. The primary winding must take this much power from the power line and since the voltage at the power line is 120 volts then the current must be 240 watts divided by 120 volts = 2 amps.

(v) No. Step-up type audio transformers were used in the early days of radio when the gain that could be obtained with a single vacuum tube was comparatively low. By using a step-up type transformer some increase in voltage could be obtained in the transformer and this helped obtain a reasonable voltage amplification in the stage. However, with modern tubes and transistors, adequate gain can be obtained in a stage without resorting to step-up transformers.

(w) Audio transformers are most widely used in electronic equipment as impedance-matching devices. They are used to match the impedance of one stage to the impedance of the following stage, and they are also used to match the impedance of the output stage to the loudspeaker voice coil impedance.

(x) The output stage of a radio or TV receiver must be matched to the speaker voice coil in order to get maximum power transfer from the output stage to the speaker voice coil.

(y) A transformer with a tapped secondary. The center tap on the secondary is either grounded or used to feed bias to the push-pull stages and the signals supplied to the stages are 180° out of phase, so when the current is increasing in one stage of a push-pull amplifier it is decreasing in the other.

(z) The turns ratio must be 10:1. The turns ratio is equal to the square root of

$$\frac{Z1}{Z2}$$

Substituting 1000 ohms for Z1 and 10 ohms for Z2 we find that the turns ratio is

$$\frac{1000}{10} = \sqrt{100}$$

$$\sqrt{100} = 10$$

(aa) An autotransformer is a transformer that consists of a single winding with a tap.

(ab) An autotransformer can be either a step-up transformer or a step-down transformer. If the primary voltage is applied across the entire winding and the secondary voltage taken off between the tap and one of the primary connections, the transformer will be a step-down transformer. On the other hand, if the primary voltage is applied between the tap and one of the outside connections and the secondary voltage taken off across the entire winding, the output transformer will be a step-up transformer.

(ac) The disadvantage of an autotransformer is that the primary and secondary windings are not completely isolated from each other electrically.

(ad) An rf transformer is a radio frequency transformer used between radio frequency amplifier stages.

(ae) RF transformers have either an air-core or a powdered iron core.

(af) The secondary winding of an i-f transformer, along with the capacitor connected across it, form a series-resonant circuit. This results in a high circulating current and a resonant voltage step-up across the coil and across the capacitor. As a result, the voltage across the coil will be considerably higher than the source voltage. We refer to this increase in voltage as resonant voltage step-up and it explains why the voltage across the secondary winding of an i-f transformer is higher than the voltage across the primary winding.

(ag) A filter choke has only one winding and therefore it has only two leads. Transformers usually have two or three windings and therefore will have more than two leads.

(ah) The filter choke is used in conjunction with filter capacitors to help smooth the pulsating dc from the rectifier output to pure dc.

(ai) The excessive current may over-heat and burn out the wire used to wind the filter choke. In addition, the filter choke may become saturated, even if it doesn't burn out, due to the excessive current flowing through it and its effectiveness as a filter will be reduced.

(aj) A filter choke offers a low resistance to the flow of dc through it. The only opposition the choke offers to dc is the resistance of the choke which is equal to the resistance of the wire used to wind the choke. On the other hand, a filter choke offers a high opposition to the flow of ac through it.

(ak) The two filter chokes are known as the input choke and the output filter choke. The choke connected to the rectifier is the input filter choke, and the other choke is the output filter choke.

(al) A swinging choke is a choke made with a small air gap in the core. The choke is usually somewhat smaller than it would normally be for the amount of current flowing through it and as a result the choke saturates easily. Its inductance varies as the current flowing through it changes.

(am) SPST means single-pole single-throw. With this type of switch there is only one circuit and in one position the switch is closed and in the other position it is open.

(an) SPDT means single-pole double-throw. With this type of switch one circuit can be completed with the switch in one position and a second circuit can be completed with the switch in the other position.

(ao) DPDT means double-pole double- throw.

(ap) A current flowing through the relay coil produces a magnetic field which attracts a bar which is pivoted above the magnet. The magnet pulls the bar towards the magnet and the the bar closes the relay contacts.

(aq) A time-delay relay is a relay in which the contacts do not close when the relay is at first energized until after a predetermined time has elapsed. This type of relay is frequently found in transmitting equipment - its purpose is to permit the tubes to come up to operating temperature before the high voltages are applied to the tubes.

(ar) An overload relay is a relay used for protective purposes. The relay contacts are normally closed, but if the current flowing through the relay coil exceeds a certain predetermined value the relay contacts will open protecting the circuit in which the relay is used.

(as) No; overloads of this type are thermal overloads and operate when the current flowing through them causes the metal conductor to reach a certain temperature. This causes the metal to spring the contacts open. An overload device of this type is called a thermal overload and is not a relay.

Lesson Questions

Be sure to number your Answer Sheet B109.

Place your Student Number on every Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time, or you may run out of lessons before new ones can reach you.

1. What do we mean when we say a magnetic circuit is saturated?

2. Name the three types of core losses encountered in iron-core transformers.

3. If the primary of a 1:3 step-up transformer is connected to a 120-volt power line, what voltage will be produced across the secondary?

4. If we connect a 200-ohm resistor across the secondary of a 1:2 step-up transformer, and then connect the primary to a 100-volt source, what will the primary current be?

5. What is the big disadvantage of interstage audio transformers?

6. What must the turns ratio be of the matching transformer used to match a tube with an output impedance of 1600 ohms to a 16-ohm speaker?

7. Why are transformers with separate primary and secondary windings more suitable than auto transformers in many applications?

8. Could a 10-henry, 250-ma choke be used as a replacement for a 10-henry, 200-ma choke?

9. Why is a swinging choke often used as the input choke in a two-stage filter network?

10. What does the abbreviation DPDT mean?

DETERMINATION

Did you ever watch a modern, diesel earthmover-- one with 10 times the horsepower of a car and rubber tires as tall as a man? Wasn't it a thrill to see that great machine level obstacles in its path, leaving a perfectly smooth roadway? The word "determination" always brings to mind that picture of an earthmover -- a machine which goes places once the throttle lever is thrown.

So, too, are you determined to go places, to achieve success and happiness. One by one you are completing your lessons, studying hard and making sure you understand everything; step by step you are approaching that greatest of all goals -- SUCCESS.

Of course, the way is long and not always easy. But whenever the going gets a little tougher than usual or you feel a bit discouraged, just bring out that old determination, and back it up with every single ounce of ambition you have.

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ACHIEVEMENT THROUGH ELECTRONICS

HOW VACUUM TUBES WORK

B110

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HOW VACUUM TUBES WORK

B110

STUDY SCHEDULE

By dividing your study into the steps given below, you can get the most out of this part of your NRI Course in the shortest possible time. Check off each step when you finish it.

☐ 1. **Introduction** .... **Pages 1 - 3**
Electron emission is a basic part of tube operation. Here we take a look at the different types of emission.

☐ 2. **The Diode Tube** .... **Pages 4 - 12**
You learn how a diode is made and how it works.

☐ 3. **The Triode Tube** .... **Pages 12 - 20**
You learn how adding a third element to a tube makes it possible for the tube to be used as an amplifier.

☐ 4. **Tube Characteristics** .... **Pages 20 - 29**
You study the characteristics of a tube, how they are pictured, and how they can be analyzed by using equivalent circuits.

☐ 5. **Multi-Element Tubes** .... **Pages 29 - 37**
You study screen-grid, pentode, and other tube types.

☐ 6. **Special Tube Types** .... **Pages 37 - 45**
Here we discuss gas-filled diodes, thyratrons, cathode-ray tubes, and other special types.

☐ 7. **Answers to Self-Test Questions** .... **Pages 45 - 48**

☐ 8. **Answer the Lesson Questions.**

☐ 9. **Start Studying the Next Lesson.**

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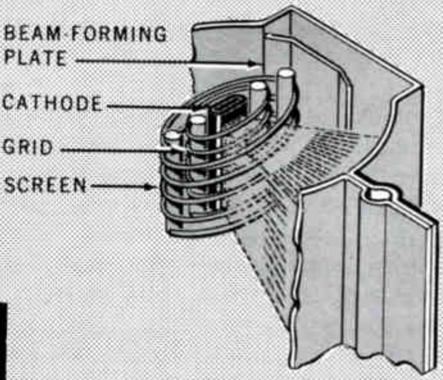

HOW VACUUM TUBES WORK

Vacuum tubes are used not only in radio and TV entertainment broadcasting, but also in commercial radio equipment, telephone repeater systems, diathermy equipment, and in many types of industrial electronic equipment. Although transistors have taken over many of the jobs originally done by tubes, there are still many applications where the vacuum tube is superior to the transistor. Even in those applications where the transistor is superior to the vacuum tube, there are many older pieces of electronic equipment still in use using vacuum tubes which you will have to service. There are other applications where a transistor could be used in place of a vacuum tube, but vacuum tubes are used because they cost less than transistors or they can be manufactured in large quantities to closer specifications than transistors can be manufactured.

There are many different sizes and shapes of vacuum tubes. Some tubes are so small they are scarcely larger than a thumbnail; other tubes found in large radio and TV transmitters are several feet tall. Regardless of whether the tube is a miniature tube such as those found in hearing aids or a large tube such as those found in transmitters, it works on the same basic principles. In this lesson you will study tubes in detail. Later you will see how these tubes are used along with the parts you studied in previous lessons.

ELECTRON EMISSION

In the circuits you studied in previous lessons, the electrons stayed within the circuit wiring and flowed only over a solid path. For example, when you connect a resistor across a terminal of a battery, the electrons are set in motion around the circuit. Electrons flow through the resistor, the wires and the battery, but they stay within the closed circuit. Electrons do not leave the wire connecting the resistor to the battery and travel off into space around the wire, nor do they leave the resistor and move into the space around it. In a tube, however, electrons are forced to fly off into the space surrounding one of the elements in the tube. This element is called the cathode. When an electron leaves the cathode we say it is "emitted" by the cathode; the giving up of electrons by the cathode is called "emission".

You will remember that all material is made up of atoms and that one of the parts of the atom is the electron. The electrons in an atom are in a continuous state of motion. The speed and the amount of motion depend, for one thing, upon the temperature of the material. Normally the atomic force within the atom prevents electrons from escaping and flying off into space. This is true even in the case of the free electrons in a conductor that move through the conductor when current flows. However, if enough heat is supplied to a conductor, it is sometimes possible to overcome the force holding the electrons within the surface of the conductor and to drive some of the electrons off into the space surrounding it. This is what we mean by emission. This type of emission is often called "thermionic" emission; thermionic means emission by heat. Some materials give off electrons more readily and at lower temperatures than other materials. Often the cathodes of tubes are coated with these materials that will readily give off electrons at low temperatures.

Altogether there are four ways in which electrons can gain enough energy to escape from a material into the space around it. These are: (1) they can be evaporated or driven out by applying heat; (2) they can be driven off by bombardment by very small, high-speed particles such as other electrons; (3) they can be driven out of some materials by the energy in light rays; and (4) they can be jerked or pulled out by a very high positive potential placed on a nearby metallic object. All four of these methods are used in various types of electron tubes to provide the free electrons that all tubes depend upon for their operation. However, the first method, evaporation by heat, is by far the most important, and we will spend more time in this lesson on tubes using this type of emission. We will also briefly discuss the second and third types of emission.

Thermionic Emission.

As we mentioned, when electrons are driven from a metal or metallic compound by means of heat, this type of emission is called thermionic emission. Thermionic is pronounced THERM-I-ON-IK. As we mentioned, thermo means heat, ionic refers to electrons and hence the word thermionic is used to describe the type of emission where the electrons are driven from the cathode by heat.

In the operation of a vacuum tube it makes no difference where the heat comes from; if the cathode can be made hot enough it will emit electrons. However, the most convenient method of producing the heat needed is by means of a heater or filament placed inside the vacuum tube. A voltage is applied to the heater or filament and this voltage causes a current to flow through the heater or filament and causes it to heat to at least a red heat, and sometimes to a white heat. The hot filament or cathode then gives off the electrons required to operate the tube. It is important to realize the heater or filament voltage applied to the tube for the purpose of heating the tube does not actually enter into the operation of the tube in any way except to provide the energy necessary to heat the cathode. If instead of using electrical energy to heat the cathode we were able to heat the cathode with a gas flame, the heater or filament voltage could be removed entirely and the tube would perform just as well.

The terms heater, filament and cathode might be somewhat confusing at this time. A cathode is an electrode which gives off electrons. It is heated by means of an element called a heater. A filament is a combination heater and cathode. We will go into this in detail in the next section of this lesson.

Secondary Emission.

When electrons are driven off a metal by bombarding the metal with high-speed particles such as other electrons, we refer to this type of emission as secondary emission. What happens in this type of emission is that a particle travelling at a very high speed strikes the metal object with such force that it is able to dislodge a number of electrons from the material. These dislodged electrons fly off the material into the space surrounding it. You will see later that this type of emission is not always desirable; as a matter of fact, it creates a problem in some vacuum tubes.

Photoelectric Emission.

When electrons are driven out of the material by the energy in light rays, this type of emission is called photoelectric emission. Photoelectric tubes are used in the motion-picture industry in connection with the sound track. A sound track is put on the side of the film. Light passing through this sound track strikes a photoelectric tube. The density of the sound track varies as the speech or sound originally recorded on the film varies. This causes the amount of light striking the photoelectric tube to vary, which in turn varies the number of electrons emitted.

Photo-emission is not often encountered in radio and TV servicing, but it is of importance to the industrial electronics technician. Even the radio-TV serviceman should know something about it, because photoelectric tubes have been used in the past in radio-phono combinations. In addition, you may have occasion to service the sound system of a home movie projector.

Now let's see how tubes work. You already know something about how a vacuum tube operates. However, in the explanations we have given you previously, we have left out many details in order to approach the subject gradually. Now we will learn more about tubes by studying all these details. Let us start by studying the simplest tube.

The Diode Tube

The simplest tube has only two elements, one to give off the electrons and another to receive them. The element that gives off the electrons is called the cathode, and the element that receives the electrons is called the plate or anode. A simple tube having only two elements is called a diode.

Other tubes have other elements in addition to these two. Therefore as we study the diode, remember that tubes with more than two elements are really diodes with additional elements added.

TUBE CATHODES

Tube cathodes can be divided into two types, those that are directly heated and those that are indirectly heated. Directly heated cathodes are called filament-type cathodes or, more frequently, simply filaments. This type of cathode was used in early vacuum tubes and is still used in tubes designed for battery operation, and in large transmitting tubes. Indirectly heated cathodes are simply called cathodes.

Filament-Type Cathodes.

The schematic symbol used to represent a filament type of cathode is shown in Fig. 1. The voltage used to heat the filament is applied directly between the two leads from the filament.

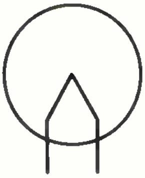

Fig. 1. Schematic symbol used to represent a filament type of cathode.

In large transmitting tubes the filament is made either of pure tungsten or of a mixture of tungsten and thorium. The very large transmitting tubes generally have a pure tungsten filament. Tungsten is a metal that can be operated at very high temperatures. Most electric light bulbs manufactured today have a large percentage of tungsten in the filament that is heated to a very high temperature to give off light.

The filaments used in many of the smaller transmitting tubes are made of a mixture of thorium and tungsten and are called thoriated filaments. The addition of thorium to the tungsten provides a material that will give off electrons at a somewhat lower temperature than pure tungsten. Thus the amount of power required to heat the filament is lower than for a pure tungsten filament. Thoriated tungsten is not as suitable as pure tungsten in large transmitting tubes. The very high voltages used on these tubes can pull the thorium right out of the filament and thus destroy the tube. In smaller transmitting tubes the voltages used are not high enough to do this.

Filament-type receiving tubes designed for operation in portable receivers were widely manufactured at one time. The filaments of these tubes were coated with oxides of certain metals. This type of filament is called an oxide-coated filament and it has the characteristics of giving off electrons at a still lower temperature than a thoriated filament. Thus the filament power required by this type of tube is even less than that required by the thoriated filament.

Even though filament-type receiving tubes operated on comparatively low voltages and required only a very small current, the fact that the heater power served no useful purpose led to the disappearance of this type of tube. Modern portable receivers all use transistors since no filament power is required. However, you may occasionally run across an older portable receiver that some set owner is particularly fond of and have to fix this receiver. Generally, filament-type tubes are available for replacement purposes.

Oxide filaments are found in some small transmitting tubes used in mobile applications. However, if the voltage applied to the tube exceeds 500 volts by very much, the oxide on the filament may be pulled off by this voltage and therefore oxide-coated filaments will be used only in small transmitting tubes.

The filaments of transmitting tubes that are made of either tungsten or thoriated tungsten can be operated on either ac or dc. However, the oxide-coated filament used in small tubes designed for use in battery-operated equipment are usually made very small and thin in order to keep the filament power required as low as possible. If these filaments are operated from ac, as the ac drops to zero and then rises to a maximum value twice during each cycle, the current flowing through the filament will vary, causing the temperature of the filament to vary. This will cause a variation in emission from the filament resulting in hum. Therefore the filament of small transmitting tubes and the older obsolete portable receiver types must be operated from dc.

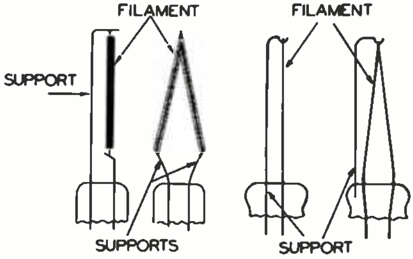

Fig. 2. Typical filaments.

The filament of a vacuum tube must be supported so it will stay in position. Typical filaments showing the type of support used are shown in Fig. 2. It is important that the filament be held tight so that it cannot sag and short to nearby elements in the tube. As a matter of fact, if the position of the filament changes, even though the filament may not touch any other elements in the tube, the characteristics of the tube will change because there are several tube characteristics that depend upon the spacing between the filament and the other elements in the tube.

Indirectly-Heated Cathodes.

The schematic symbol used to represent an indirectly heated cathode is shown in Fig. 3. The indirectly heated cathode is simply called a cathode. Notice that in addition to the cathode we have another element drawn beneath the cathode in the schematic symbol. This is the

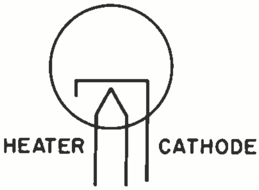

Fig. 3. Schematic symbol used for a heater and indirectly heated cathode.

heater, which is used to heat the cathode. Sometimes this is loosely called a filament because of its similarity to the filament we have just discussed and because the first tubes had directly heated cathodes. In fact the transformer winding used to supply heater voltage is still often called the filament winding.

The cathode is built in the form of a hollow cylinder like those shown in Fig. 4. The heater is placed inside of this hollow cylinder. Voltage is applied to the heater, and the heat produced by the heater is radiated and in turn heats the cathode.

The cathode is usually coated with oxide. This is done in order to provide an abundant supply of electrons at low operating temperatures. This type of cathode is used only in receiving tubes or small transmitting tubes where the applied voltage is not high enough to pull the oxide material off the cathode.

In many schematic diagrams of circuits in which an indirectly heated cathode type of tube is used, the heater is omitted. The heater actually serves no useful purpose as far as the operation of the tube is concerned, other than to heat the cathode. It does not enter into the characteristics of the tube and therefore the heater connections can be omitted to simplify the schematic diagram. The connections to the other elements in the tube are the ones that actually determine what the tube will do and how it will operate. We will follow this practice in many cases so we can emphasize the operating circuits.

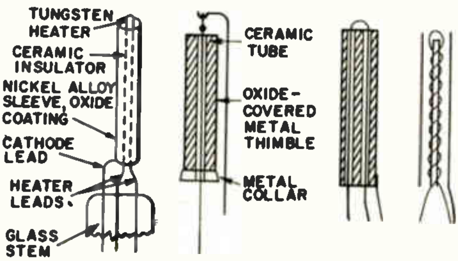

Fig. 4. Indirectly heated cathodes.

Operating Voltages.

The filament or the heater of a vacuum tube is designed to operate on a certain definite voltage. The first number used to identify receiving tubes gives an indication of the heater or filament voltage. For example, a 12L6 tube operates on a heater voltage of approximately 12 volts. The exact voltage is 12.6 volts. The number preceding the first letter indicates the heater voltage. A 35Z5 tube requires a heater voltage of 35 volts. A 6F6 tube requires a heater voltage of 6.3 volts, and a 2BN4 tube requires a heater voltage of 2.3 volts. Keep this in mind; it will be helpful to you when you start doing service work. The first number or group of numbers preceding the letters in the tube designation is an indication of the filament or heater voltage for which the tube was designed. This system is followed only for modern receiving tubes. Older receiving tubes did not use this system, and transmitting and industrial tubes do not use it.

THE PLATE

In the first vacuum tubes made, the anode that received electrons emitted by the cathode was simply a flat piece of metal, and hence was called a plate.

In modern vacuum tubes the plate completely surrounds the filament or cathode. The shape of the plate

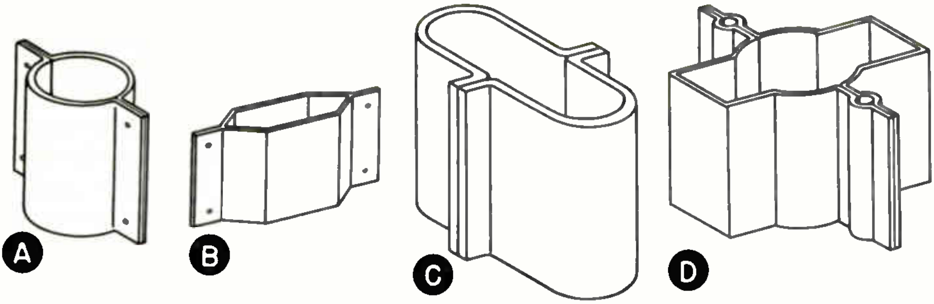

Fig. 5. Typical plate structures.

depends to some extent on the type of cathode used. If the cathode is simply a round cylinder, then the chances are that the plate will also be a round cylinder. However, if a filament type of cathode is used, such as those shown in Fig. 2, the plate will usually be rectangular in shape. Typical plate structures are shown in Fig. 5.

Vacuum tube plates may be made of any of several different materials, such as nickel, molybdenum, carbon, iron, tungsten, tantalum, and graphite. Zirconium is also sometimes applied as a coating on the plate. The plates of most receiving tubes and small transmitting tubes are made of nickel, which can easily be formed into the desired shape.

The plate of a vacuum tube is subjected to a certain amount of heating. Part of this heat comes from the filament or cathode, and part of it is produced by the electrons striking the plate. These electrons striking the plate can cause considerable heating; as a matter of fact in some transmitting tubes they produce so much heat that the plate becomes a bright red color.

The fact that the plate is heated results in a few additional problems. First, if the plate gets hot enough it will give off electrons, and if this happens the tube may not work properly because electrons may be able to travel both ways through it. The tube would simply act like a resistor. Therefore steps must be taken to keep the plate below the temperature where it will emit electrons. This is not too big a problem in small receiving tubes, but in the larger tubes it can be quite serious. The plate is often given a dull black finish because a black surface radiates heat readily and therefore will be cooler than a polished surface. The plates of many transmitting tubes are fitted with fins to provide a larger surface to dissipate or get rid of the heat produced at the plate of the tube. Large transmitting tubes are often water-cooled. As a matter of fact, in some large broadcast stations the water used to cool the tubes in the transmitter is used to heat the building in the winter.

Even if the plate is kept cool enough to prevent thermionic emission, the electrons travelling from the cathode of the tube over to the plate can pick up enough speed to strike the plate so hard that they will knock other electrons loose from the surface of the plate. Remember, this is one of the types of emission we discussed before and it is called secondary emission. The electrons that are knocked off the plate of the tube in this way leave the plate at a rather low speed. The plate normally has a positive voltage applied to it and the electron is negative, so in a diode tube, if the plate is positive, the electrons are simply attracted back to the plate. Secondary emission does not cause any difficulty in a diode. However, you will see later that in tubes having additional elements, secondary emission can be a problem.

Another problem that is created when the plate of a tube becomes very hot is that almost all metals have a certain amount of gas trapped right in the metal. When a metal plate becomes very hot, the gas trapped in it may be forced out of the metal and into the space surrounding the plate of the tube. Gas in a tube can destroy its usefulness. Now let's see why it is important that the amount of gas in a tube be kept as low as possible.

GAS EVACUATION

Tubes are called vacuum tubes because all the gases inside the tube including air are normally evacuated. There are two important reasons why these gases must be removed from inside the tube. First, if air is permitted in the tube, the filament or heater will oxidize; in other words, it will simply burn up when heated. Secondly, even if this problem could be overcome, there is another important reason why all gases must be removed from the tube. Gases are made up of molecules. Although these particles are extremely small, they are nevertheless many times the size of an electron. An electron traveling from the cathode of the tube to the plate moves at a fairly high speed. The chances are that the majority of electrons traveling from the cathode to the plate would strike one or more gas molecules if there were a large amount of gas in the tube. If a high speed electron strikes a gas molecule the electron will be deflected from its path and it will knock electrons out of the gas molecule.

Normally a gas molecule has no charge. However, if it is struck by an electron, which knocks other electrons out of the molecule, the molecule will be short of electrons, and hence will have a positive charge. We call positively charged molecules "ions". These ions are large and heavy in comparison to electrons and have a fairly high positive charge on them. Since the cathode of the tube is normally connected to a negative voltage source, it is negative, and will attract these positive ions. As a matter of fact, the positive ions will pick up a fair amount of speed traveling to the cathode and may bombard it with such force that small particles of the cathode material will be knocked loose.

Gas inside a vacuum tube is extremely undesirable. Therefore, in the manufacturing process, every effort is made to remove all the gases from inside the tube. However, some of the gas will remain in the tube and additional gas will boil out of the materials from which the tube is made the first time the tube is heated. To get rid of these gases left in the tubes a "getter" is placed inside the tube.

A getter is a small cup containing chemicals. During the manufacturing process, the tube is first evacuated by means of pumps. This will remove most of the gases from the tube. The tube is sealed and then it is heated. In the heating process gases are driven off the metals inside the tube such as the cathode and the plate. At the same time, the getter is heated and the chemicals in the getter combine with any gas molecules released, forming metal compounds, which are deposited on the glass envelope of the tube. The compounds in the getter hold onto the gas molecules and will not easily release them into the space inside the tube again. The silvery appearance that many tubes have near the base of the bulb is produced by the compounds forming on the glass envelope of the tube.

By using this procedure it is possible to obtain an excellent vacuum in tubes with a pure tungsten filament. The vacuum inside a tube with a thoriated tungsten filament is not quite as good, and the vacuum inside tubes with oxide-coated filaments is still poorer. The reason for this is that you can heat a tube with a pure tungsten filament to a higher temperature than you can the other types and hence the action of the getter is even more complete in these tubes than it is in the other types.

For this reason, tubes with thoriated tungsten filaments or oxide-coated cathodes are limited to uses where the operating voltages are somewhat lower than those that can be applied to pure tungsten filament tubes.

The leads connected to the various elements inside the tube are brought through glass seals. The glass is heated to a high temperature and it flows around the leads, providing a nearly perfect seal. Thus once the tube is evacuated, it is almost impossible for air to leak back into the tube. We say almost impossible because there is no such thing as a perfect seal and air will gradually leak back into the tube. It may take several years for enough air to get into the tube to affect its performance, but if the tube is left around unused long enough, eventually enough gas will get into the tube so that its operation will be impaired.

Tubes that have had all the gas removed from inside them are called hard tubes. Most tubes found in radio and TV receivers are hard tubes. However, there is another group of tubes into which certain types of gas have been deliberately introduced. Mercury is put inside some diode tubes. When these tubes are operated, the mercury will heat and vaporize, filling the inside of the tube with mercury vapor. This type of tube is called a soft tube or a gaseous tube. Other gases are sometimes used, but mercury vapor is the gas you will be most likely to encounter. It is easy to identify a mercury vapor tube because mercury gives off a characteristic blue glow. Therefore, if you see a tube operating with a bright blue glow, the chances are it is a mercury vapor tube.

If there is excessive gas inside a hard tube it also will have a blue glow. However, the blue glow is not as bright as it is in a mercury vapor tube. Mercury vapor tubes are almost always diode tubes, although a special type called a thyratron has three elements and hence is a triode. These tubes are usually quite easy to pick out. If you discover a blue glow between the elements of a hard tube, the tube is gassy and should be replaced.

Before leaving this subject there is one other point that should be brought out. Electrons emitted from the cathode of a hard tube frequently travel at a high speed and miss the plate of the tube and strike the glass envelope. When they do this there will often be a blue glow on the envelope of the tube. This does not indicate a defect in the tube. If a hard tube shows this blue glow on the envelope of the tube you can forget about it; it does not mean anything. However, if the blue glow appears between the elements of a hard tube, the tube is gassy.

CHARACTERISTIC CURVES

Among the information published by vacuum tube manufacturers are the characteristic curves of their tubes. These curves make it possible for the engineer or technician to predict how the tube will perform under a given set of operating conditions. The characteristic curve of a diode tube shows how much current will flow when a given voltage is applied to the plate of the tube. A typical diode characteristic curve is shown in Fig. 6.

Notice that this characteristic curve is not a straight line. It is bent on the two ends. Also notice that there is a very small current flow even when the plate voltage is zero. This is because a few of the electrons emitted by the cathode travel with sufficient velocity to reach the plate even without a positive voltage on the plate. As the plate voltage is slowly increased from zero to a high positive value the number of electrons flowing to the plate gradually increases. At first the increase is non-linear, but as the plate voltage is increased still further, eventually a point is reached where the characteristic curve becomes quite linear. By this we mean the curve is a straight line which indicates that we will get an almost constant change in plate current for a given change in plate voltage. For example, on a linear curve, if increasing the plate voltage from 25 to 50 volts causes an increase in current of 5 milliamperes, we can expect an increase in plate current of 5 more milliamperes when we increase the plate voltage from 50 volts to 75 volts. Again, if we increase the voltage from 75 volts to 100 volts and the curve is linear, we can expect another 5 milliampere plate current increase.

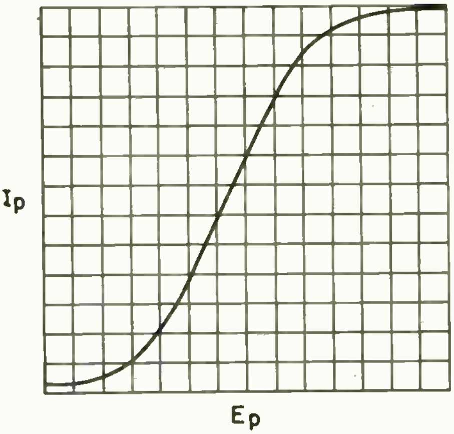

Fig. 6. Characteristic curve of a diode showing the relationship between plate current and plate voltage. Notice that there is a small plate current even when the plate voltage is zero. This is caused by a few electrons being emitted by the cathode at such a high speed that they travel over and strike the plate even when no voltage is applied to it.

Notice that the top of the curve begins to round out and become flat--this is called plate current saturation. Eventually a point is reached where all of the electrons emitted by the cathode are drawn immediately to the plate of the tube. In other words, the electrons do not form a space charge or electron cloud around the cathode, but instead travel immediately from the cathode of the tube right over to the plate. When this point is reached, increasing the plate voltage still further will result in no further increase in the plate current flowing in the tube because the plate is pulling all the free electrons over to it and is gathering them up as fast as the cathode can emit them. As a matter of fact, if the plate voltage is increased beyond this point, there is the danger that some electrons will be emitted from the cathode by the process of jerking them out of the cathode by the high plate voltage. This may cause small particles of the cathode material to jerk loose, and if this happens the cathode of the tube will soon disintegrate and the tube will no longer be usable.

SUMMARY

There are a number of important things you should remember in this section. First, the cathode found in tubes can be divided into two types-- the directly heated cathode which is called a filament, and the indirectly heated cathode, which is simply called a cathode. Remember that the heater used to heat an indirectly heated cathode performs no useful purpose other than to heat the cathode of the tube. It does not enter into the electrical circuit and operation of the tube itself.

Three types of cathode material are found in vacuum tubes: pure tungsten, thoriated tungsten, and oxide coatings.

Several different types of plates are used in vacuum tubes; the exact shape of the plate is usually determined by the shape and type of cathode used in the tube. The plate of a vacuum tube will give off electrons by thermionic emission if it becomes too hot. However, some transmitting tube plates can operate at a red temperature without giving off electrons, the materials used in the manufacture of the plates of these tubes are selected because they give off electrons only at a very high temperature. The plate may also give off electrons due to secondary emission. In some tube types this can become a problem.

The inside of a vacuum tube is normally highly evacuated. A tube with a high vacuum is called a hard tube. Gas is deliberately introduced into some tubes, and these are called soft tubes.

SELF-TEST QUESTIONS

(a) Name the two elements found in a diode tube.

(b) Into what two types can tube cathodes be divided?

(c) What is the name given to a directly heated cathode?

(d) How is the cathode of an indirectly heated tube heated?

(e) Why is the cathode of a receiving-type tube usually coated with an oxide?

(f) What useful purpose does the heater of an indirectly heated tube serve other than to heat the cathode of the tube?

(g) Approximately what would you expect the heater voltage to be of a type 8AC9 tube?

(h) What are the two names given to the element in the diode tube that receives the electrons?

(i) What two things cause the plate of a vacuum tube to be hot?

(j) What two undesirable things may happen if the plate on a vacuum tube becomes excessively hot?

(k) What is the purpose of a getter inside a vacuum tube?

(l) What is meant by a hard tube?

(m) What is a soft tube?

(n) What does a small blue glow appearing on the glass envelope of a hard-type tube indicate?

(o) What do we mean when we say that the plate current - plate voltage curve of the diode is linear over most of its range?

The Triode Tube

The development of the diode or two-element tube merely opened the door to the field of electronics. The diode tube has only limited applications. It can be used as a rectifier to change ac to dc, and in some other special circuits, but it cannot be used to amplify.

Early in the start of the twentieth century, the triode tube was developed. This tube touched off the rapid development in electronics that has occurred since then. The development of the triode tube led to the development of other multi-element tubes which have made possible circuits undreamed of not too many years ago.

You have already been introduced to the triode and know that the triode tube has three elements: a cathode, a grid, and a plate. The introduction of the grid between the cathode and the plate of the tube made it possible for a vacuum tube to amplify weak signals. You already have a general idea of how the grid works, but in this section we will review this idea, expand it, and then learn more about tube characteristics. It is extremely important for you to understand all the details of how a triode tube works, because the multi-element tubes that you will study later are simply triodes with additional elements added.

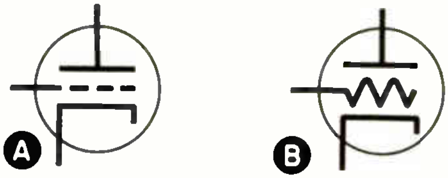

Fig. 7. Different ways of representing the grid on schematic diagrams.

HOW THE GRID WORKS

The third element inside the vacuum tube is placed between the cathode and plate and is called the grid. As the name implies, the grid is of open construction. The schematic symbol used to represent a grid is shown in Fig. 7A. On some old diagrams you might find the symbol shown in 7B used - this symbol is obsolete.

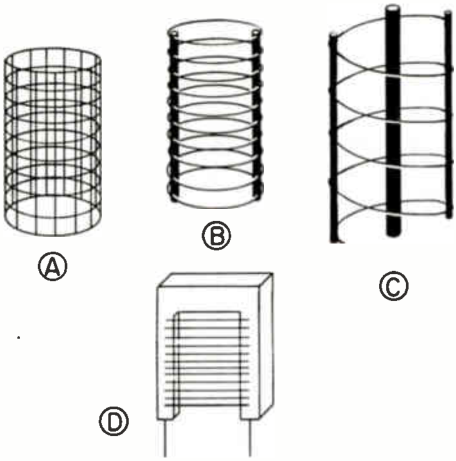

Fig. 8. Different types of grid structures.

Several different types of grid construction are shown in Fig. 8. Notice that in A the grid is made in the form of a spiral mesh, like a screen, whereas the grid shown in B is made up of a spiral-wound coil with the turns placed relatively close together. In C the same type of construction is used as in B, but the space between the turns is much greater. In D the grid is more or less rectangular in shape and is supported by the U-shaped elements at the end so that the grid is held in a very rigid position. The grid is supported by the frame and this type of construction is often referred to as a frame grid. It has this advantage over the other types: the grid wires can be placed very close together and very close to the cathode, which as you will see later makes it possible to make a tube with a much higher gain than that of the other types of grid.

Before we review how the tube amplifies, let's consider the effect of the grid on the flow of plate current when different voltages are applied to it. The first case we will take up is where the grid is connected directly to the cathode so that the voltage applied to it is zero.

Zero Grid Voltage.

When the grid is connected directly to the cathode we have the arrangement shown in Fig. 9. Here the plate is connected to the positive side of the B battery and the cathode is connected to the negative side of the battery. The grid is connected directly to the cathode, and a small battery is used to provide the heater voltage required to heat the heater, which in turn heats the cathode of the tube.

When the cathode is heated, it will emit electrons and they will fly off into the space surrounding the cathode. These electrons will form a cloud of electrons around the cathode. This cloud of electrons is called a space charge. Some of the electrons in the space charge will fall back to the cathode, others will be attracted by the positive potential applied to the plate of the tube and they will be drawn through the grid wires to the plate. A few electrons in travelling from the cathode

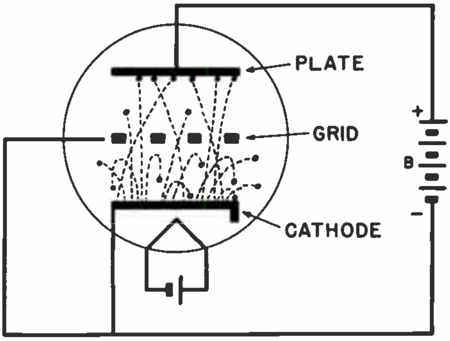

Fig. 9. When there is no grid bias, an average number of electrons flow to the plate, and the rest form a space charge between the cathode and the grid.

to the plate of the tube may accidentally strike the grid wires. These electrons will flow through the external circuit from the grid back to the cathode of the tube. As long as the grid is connected directly to the cathode, the tube acts very much like a diode and the grid has very little effect on the flow of plate current. The amount of plate current flowing will depend primarily upon the voltage applied between the plate and cathode of the tube and the spacing between the plate and cathode.

Positive Grid Voltage.

Now if we modify the circuit shown in Fig. 9, by adding a small C battery in the grid circuit as shown in Fig. 10, we will have a positive voltage on the grid of the tube. This means that the grid will be slightly positive with respect to the cathode. The B battery used between the plate and cathode has a much higher voltage than the C battery, and therefore the plate will have a much higher positive potential than the grid.

With the C battery connected in the grid circuit, the positive voltage on the grid of the tube will attract electrons from the space charge around the cathode and start these electrons speeding toward the grid. By the time the electrons travel the short distance from the space charge to the grid most of them will be travelling at such a high speed that they will pass right through the grid wires and then come under the influence of the high positive voltage on the plate of the tube. Most of the electrons will therefore continue travelling towards the plate of the tube until they eventually will reach and strike the plate.

The number of electrons reaching the plate will be much higher than it was in the preceding case where there was no voltage applied to the grid. The grid is able to increase the number of electrons flowing to the plate because the grid is placed very close to the cathode, and even though there is only a low positive voltage applied to the grid it is able to pull many electrons from the electron cloud and start them on their way to the plate.

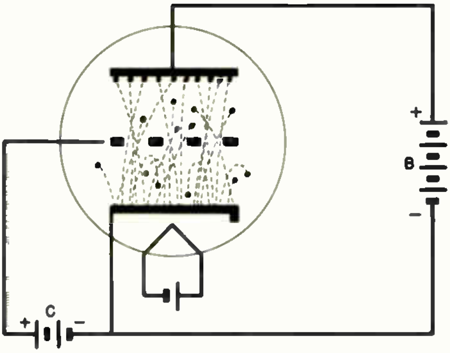

Fig. 10. Making the grid positive greatly increases the number of electrons moving to the plate.

Because the grid has a positive voltage applied to it, there will be more electrons striking the grid than there were in the preceding case when there was no voltage applied to the grid. However, even though a few electrons will be attracted to the grid, a small positive voltage applied to the grid will increase the flow of plate current. If the positive voltage is made higher, in other words if the grid is made more positive, it will start to attract more and more electrons. Eventually a point will be reached where the grid will be taking many of the electrons that would normally flow over to the plate of the tube. Then, instead of causing the plate current to increase, the large number of electrons flowing to the grid of the tube will starve the plate so that the plate current will be less than it would be if the grid were operated at zero potential.

When the number of electrons striking the grid becomes high, the energy that these electrons give to the grid upon striking it may cause the grid to become very hot. As a matter of fact, if enough electrons strike the grid, the grid will become red hot. Keep this in mind. If you see a vacuum tube where one of the grids is showing a red heat, the number of electrons reaching the grid is too high--there is something wrong in the circuit.

Negative Grid Voltage.

If instead of putting a positive voltage on the tube grid, you put a negative voltage on it, you will have the circuit shown in Fig. 11. Now the negative potential on the grid of the tube repels the electrons coming from the space charge and drives them back to the space charge so that the number of electrons getting through the grid and reaching the plate of the tube is greatly reduced. As a matter of fact, if the negative voltage applied to the grid of the tube is made high enough, all electron movement between the cathode and the plate will be stopped --there will be no flow of electrons from the cathode to the plate of the tube.

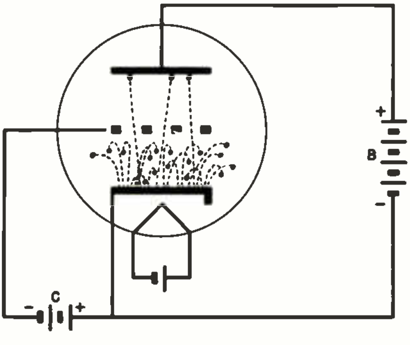

Fig. 11. Making the grid negative reduces the number of electrons moving to the plate.

Amplification Factor.

Current is actually a movement of electrons, and since the grid controls the electrons flowing from the cathode to the plate of the tube, the grid can control the current flowing from the cathode to the plate. The current flowing in the plate circuit is called the plate current. Changing the plate voltage on a triode tube will cause the plate current to change, but because the grid is closer to the cathode than the plate, it exerts a greater effect on plate current than the plate does. As a matter of fact, we may have to change the plate voltage on a tube as much as 100 volts to get the same change in plate current that can be obtained by changing the grid voltage only 1 volt. The exact ratio between the change in plate voltage and the change in grid voltage needed to get the same change in plate current is called the amplification factor. If we have to change the plate voltage 50 volts to get the same change in plate current we can get by changing the grid voltage 1 volt, the amplification factor is $\frac{50}{1} = 50$. A triode tube may have an amplification factor somewhere between 5 and about 100. The amplification factor of a tube depends primarily upon the ratio of the plate-cathode spacing to the grid-cathode spacing.

The amplification factor of a triode tube is a very important characteristic of the tube. It is a good indication of how much voltage gain you can expect to obtain from an amplifier stage using the tube. The total amplified voltage produced by the tube is equal to the amplification factor times the signal voltage applied between the grid and the cathode of the tube. It is not possible to get all of this amplified voltage out of the tube, because the tube has internal resistance, and part of the voltage will be dropped across this resistance, but in general the higher the amplification factor of a tube, the greater the gain we can expect to obtain from the tube.

To provide a short form for expressing the amplification factor of a tube, the Greek letter, mu, which is pronounced "mew", and written μ, is used as a symbol to represent the amplification factor. The amplification factor is often referred to as the mu of the tube. Thus a high-mu tube is a tube with a high amplification factor.

HOW A TRIODE AMPLIFIES

You have already had a brief explanation of how a triode amplifies a signal, so this will be primarily a review. Be sure that you completely understand how the tube amplifies because vacuum tubes are the heart of electronic equipment and if you do not know how tubes work, you will not understand the equipment in which they are used.

First, let's consider what type of signal we may want to amplify. For example, let's assume that we have a sine-wave signal that represents a certain sound. The amplitude of the signal is extremely weak. In order to use the signal to produce sound, we must increase the strength of the signal. The usual procedure is to first build up the voltage of the signal. An amplifier stage used for this purpose is called a voltage amplifier. If we apply the signal between the grid and the cathode of a vacuum tube connected as shown in Fig. 12, we know the ac signal in the grid circuit will produce variations in the plate current. We know this is true because the voltage applied to the grid has a pronounced effect on the flow of current to the plate. Thus the varying signal applied between the grid and the cathode of the tube will cause the plate current to vary.

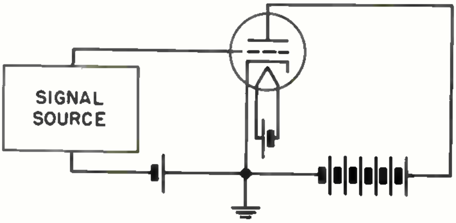

Fig. 12. The signal applied between the grid and the cathode will result in a varying plate current.

However, we are interested in a varying output voltage. If we feed a weak signal voltage into the grid of a tube to amplify it, what we want is an amplified voltage in the output. The desired result can be obtained with a circuit like the one shown in Fig. 13. Now let's stop and consider what happens in this circuit first when the signal voltage is zero.

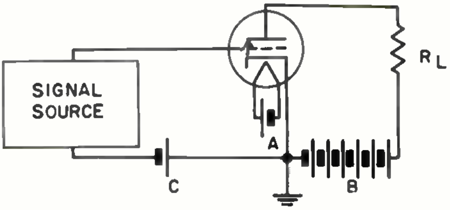

Fig. 13. The signal applied between the grid and the cathode will result in an amplified voltage in the output circuit.

When there is no ac signal applied to the input, a steady plate current will flow from the cathode of the tube to the plate of the tube. The exact amount of current is relatively unimportant, but it will depend upon the grid bias voltage supplied by the C battery, the plate voltage supplied by the B battery, the characteristics of the tube itself, and the size of the plate load resistor marked R_L.

The plate current flowing through the tube will flow from the negative side of the battery to the cathode of the tube. The heated cathode will give off electrons, which will flow through the space between the cathode and the grid of the tube over to the plate of the tube. The electrons will then flow from the plate of the tube through the plate load resistor R_L to the positive side of the battery, through the battery, back to the negative battery terminal. It sounds as though the electrons start from the negative terminal and then gradually flow around the circuit. Actually, the movement of electrons in the circuit is instantaneous. The electrons start moving in all parts of the circuit at the instant the tube is heated and power applied.

When current flows through the load resistor R_L, there will be a voltage drop produced across the resistor. The exact value will depend upon the current flow and the size of the resistor. We know this is true from Ohm's Law which states that E = IR. If there is a voltage drop across the dropping resistor, this means that the plate voltage, which is the voltage between the plate and the cathode of the tube, will be less than the B supply voltage by an amount equal to the voltage drop across the plate load resistor. Again, we know this is true because the sum of the voltage drops in a series circuit must be equal to the source voltage. In this series circuit we have the plate-cathode circuit of the tube in series with the load resistor. Therefore, the voltage across the tube equals the B supply voltage minus the voltage drop across the load resistor.

Before a signal is applied between the grid and the cathode of the tube the plate current will reach what is called a steady state. The voltage between the plate of the tube and the cathode will be some constant value.

Now let us consider what happens when a signal voltage like the sine-wave shown in Fig. 14A is applied between the grid and the cathode of the tube. Notice the first half cycle, which is numbered 1-2-3 on the input signal at A. This signal swings in a positive direction. When the ac input voltage swings positive, its polarity will be such that it will subtract from the grid bias voltage. This will make the grid voltage less negative. If we make the grid voltage less negative, we are moving it in a positive direction. When the grid becomes less negative it will allow more electrons to flow from the cathode of the tube to the plate. If the number of electrons moving in this part of the series circuit increases, then the total number of electrons in motion in all parts of

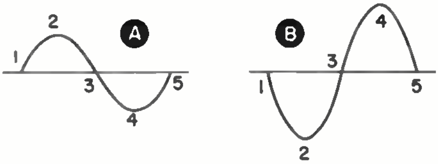

Fig. 14. A sine-wave signal voltage. The input signal is shown at A, and the output signal at B.

the series circuit must increase. The number of electrons flowing through the plate load resistor R_L increases. When this happens, the voltage drop across the plate load resistor increases, and there will be less of the B supply voltage between the plate and cathode of the tube. This means that the plate voltage will decrease.

The plate voltage will continue to decrease as the input signal moves from point 1 to point 2. The plate voltage will look like the wave shape shown in Fig. 14B and as the input moves from point 1 to point 2 on curve A, the output will move from point 1 to point 2 on curve B.

If the input signal begins to decrease from its peak point 2 back to zero voltage at point 3, the plate voltage between the plate and cathode of the tube will start to increase, because as the input signal moves from point 2 to point 3, the negative grid voltage on the tube will be increased. This means that there will be fewer electrons flowing from the cathode to the plate of the tube, and hence fewer electrons flowing through the load resistor. When the number of electrons flowing through this resistor decreases, the voltage drop across it decreases. Since the sum of the voltage drop across the load resistor and the voltage between the plate and cathode is always equal to the B supply voltage, the voltage between the plate and cathode of the tube must increase.

During the second half of the input cycle, when the input signal swings from point 3 to point 4, the signal is swinging in a negative direction, so it adds to the grid bias voltage applied to the tube by the C battery. This makes the grid even more negative, and reduces still further the number of electrons moving from the cathode to the plate of the tube. This reduction in electrons flowing in the series circuit means that there will be an even smaller voltage drop across the plate load resistor R_L and hence even more voltage between the plate and the cathode of the tube. As the input signal moves from point 3 to point 4 and then on to point 5, the output signal between the plate and cathode of the tube will follow the shape shown from point 3 to point 4 and then to point 5.

This variation in the voltage between the plate and cathode of the tube will be several times the amplitude of the input signal.

Before going ahead let's take a look at what we have in the plate circuit of the tube. Examine the waveform shown in Fig. 14B. Notice that a single ac cycle has been produced and the amplitude, frequency, and wave shape of the signal depend upon the signal applied between the grid and the cathode. This signal is an amplified version of the signal applied between the grid and the cathode of the tube.

The total signal applied between the grid and the cathode of the tube actually consists of a dc voltage applied by the C battery plus an ac voltage which is superimposed or added to it. The voltage between the cathode and grid will be the algebraic sum of the two voltages. When the signal voltage tends to swing the grid positive it will actually be subtracting from the C battery voltage so that the net negative voltage applied to the grid will be reduced. When the signal source tends to swing the grid in a negative direction, it will add to the C battery voltage so that the grid will be made more negative with respect to the cathode and will reduce the current flow through the tube.

The voltage in the plate circuit actually consists of a dc voltage applied to the tube with an ac voltage superimposed on it. Notice, however, that the ac voltage at the plate is inverted when compared to the input signal. In other words, when the input signal swings in a positive direction, the output signal swings in a negative direction, and when the input signal swings in a negative direction, the output signal swings in a positive direction. We say that the two signals are 180° out of phase.

Notice that the cathode of the tube in the circuit shown in Fig. 13 is grounded. This type of circuit is called a "grounded-cathode" amplifier. One of the characteristics of the grounded-cathode amplifier is that there is a 180° phase-shift between the input and output signals.

The signal voltage applied in series with the C bias voltage between the grid and cathode causes the plate current flowing from the cathode to the plate of the tube to vary. Actually, the current looks like a dc current with an ac current superimposed on it. Therefore, when we refer to the ac current in a tube, we mean the signal current or the variation in dc current caused by a signal applied between the grid and cathode. Remember that the current through a tube always flows from cathode to plate; it never reverses in direction. However, the variation in current through the tube due to the signal variations produces the same effect as we would have with a dc current with an ac current superimposed on it.

Remember that when you studied the amplification factor we pointed out that the amplification factor is based on a change in plate voltage and a change in grid voltage. Another way of expressing the same idea is in terms of ac voltages. We can say that it is the ratio of ac plate voltage to the amount of ac grid voltage required to produce the same ac plate current. As we mentioned previously, we are speaking of an ac current superimposed on a dc current.

SUMMARY

This section of your lesson is extremely important. Therefore we will not try to summarize it, but instead we suggest you go back and read over the entire section of the lesson again to be sure you understand it thoroughly. Read the section carefully and slowly and try to picture exactly what is going on inside the tube. Grasping clearly the idea of how a tube amplifies is extremely important. If you master this idea now, the remaining material in this book should be comparatively simple and you will also find that it will be much easier for you to understand how transistors amplify. When you are sure you understand this section of the lesson, test yourself by doing the following self-test questions.

SELF TEST QUESTIONS

(p) Why does the grid voltage have a greater effect on plate current than the plate voltage does?

(q) If the voltage applied between the grid and cathode of a triode tube places the grid positive with respect to the cathode, what effect will this have on the current flowing through the tube?

(r) If the grid is made negative

with respect to the cathode, and the voltage is slowly increased, what will happen to the plate current?

(s) What do we mean by amplification factor?

(t) Between what values would you expect the amplification factor of a triode to fall?

(u) When a signal voltage is amplified by a tube in a grounded cathode circuit, will the amplified signal be the same as the input signal?

(v) What do we mean by ac plate current?

(w) What is a grounded-cathode amplifier?

Tube Characteristics

Tube characteristics are important both to the engineer and to the technician. They are important to the engineer because he uses them in designing circuits. He must know the characteristics of the tube in order to select the correct value of parts to use along with the tube to get the best possible performance out of the circuit. They are important to the technician because often he will have to service equipment in which detailed service information is not available. By identifying the tube types used in the equipment and referring to a tube manual which describes the characteristics of the tubes used, he can obtain a great deal of useful information on how the equipment should work.

A great deal of information about tubes is given in the form of characteristic curves. The most important of these curves is the E_g–I_p (grid voltage-plate current) curve.

THE Eg-Ip CURVE

A tube is able to reproduce a signal only as long as a given change in grid voltage will produce a constant change in the plate current. Let's assume we have a tube with a voltage of 2 volts between the grid and cathode, and that the grid is 2 volts negative with respect to the cathode. If we increase this voltage from 2 volts to 2-1/2 volts, we know that the plate current will decrease. We could actually measure this change in plate current. Now, if we increase the voltage still further from 2-1/2 volts to 3 volts, we should get the same change in the plate current that we got when we changed the voltage from 2 volts to 2-1/2 volts. It is quite likely that we would get the same change, but eventually a point will be reached where changing the grid voltage 1/2 a volt will not produce this same change in plate current. When we reach this situation, we say that this tube becomes non-linear. This characteristic of a tube limits the amount of signal that can be applied between the grid and cathode of the tube.

The change in plate current that can be expected for a given change in grid voltage is shown on a curve called the E_g-I_p curve. A typical E_g-I_p curve is shown in Fig. 15. Notice how the plate current will be different for different values of grid voltage. Also notice that part of this curve is relatively straight but the two ends of the curve are quite bent. In the middle of the curve, we have a straight section that is called linear. This simply means that as long as the tube is operated within these limits a given change in grid voltage will produce the same change in plate current. As long as this change in plate current for a given change in the grid voltage remains constant, the output will be a faithful reproduction of the input signal. However, once the change becomes non-linear, the output will be distorted. This means the output signal will not be a faithful reproduction of the input signal.

Grid Bias.

The voltage applied by the C battery that is connected between the grid and cathode of a tube is called the grid bias voltage. To bias something means to fix or adjust it. The grid bias voltage fixes or adjusts the tube to operate under the most favorable conditions. The idea in back of a grid bias voltage is to apply a voltage to the grid that will place the tube operation on the desired portion of its characteristic curve. In the case of the amplifier we have been considering, we bias the tube to operate at the center of the linear or straight part of the characteristic curve. If you look at Fig. 15 you can see that the characteristic curve is comparatively straight between zero grid voltage and the grid voltage at -6 volts. Slightly to the right of zero grid voltage the curve becomes distorted, and to the left of -6 volts it also becomes distorted. Therefore, to get the tube operating on the linear part of the curve, we would apply a grid bias of -3 volts. With a grid bias of -3 volts, if the input signal drives the grid voltage 3 volts in a positive direction, we can expect the same change in plate current as we will get when the input voltage swings 3 volts in a negative direction. When the input voltage swings 3 volts in the positive direction, it will subtract from the grid bias, so the net voltage applied to the grid of the tube

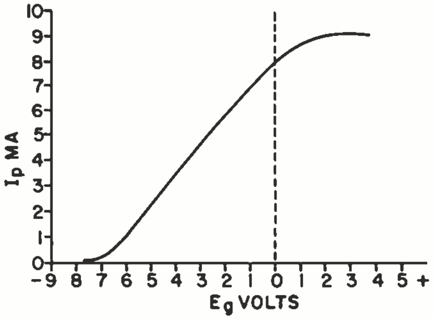

Fig. 15. A typical E_g-I_p characteristic curve.

will be zero, and when it swings 3 volts in the negative direction, it will add to the grid bias so that the net voltage applied between the grid and the cathode of the tube will be -6 volts. Changing the grid voltage between these limits produces linear or constant changes in plate current.

On the other hand, if instead of a grid bias of -3 volts we had a grid bias of -5 volts and a 3-volt input signal, when the grid swings in the positive direction we will get a total voltage of -2 volts on the grid. This will produce a change in plate current. However, when the grid swings 3 volts in the opposite direction, due to the signal, we will get a total grid voltage of -8 volts. This will produce a change in plate current, but it will not be the same as the change produced when the signal went in the opposite direction. As a matter of fact, you can see from the curve that once the signal is past -7 volts little or no change in plate current will occur.

Under these circumstances, a plate current change that is different when the signal swings in one direction is different from the plate current change when the signal swings in the opposite direction and we get distortion. This means that the signal is not reproduced faithfully. For an input signal like the one shown in Fig. 16A we would get an output signal like the one shown in Fig. 16B. Notice that in the first half cycle when the input signal swings in a positive direction the output signal swings in the opposite direction. However, the output signal is a faithful reproduction of the input signal. During the second half cycle, when the input signal swings in a negative direction, the output signal swings in a positive direction but is flattened off at the top. The amplified signal is not a faithful reproduction of the input signal. As we mentioned, this is called distortion, and this particular case of distortion is called amplitude distortion because the amplitude of one half of the cycle is compressed.

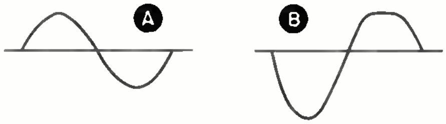

Fig. 16. The input voltage (A) and the output voltage (B) for a tube with excessive grid bias. Notice that the positive half of the cycle in the output is flattened.

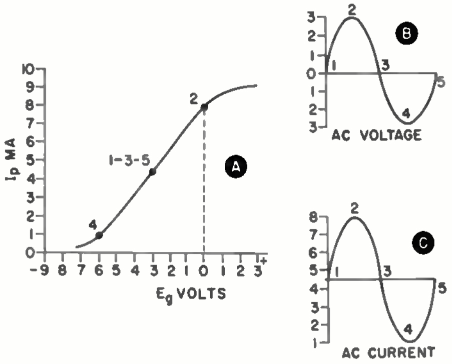

Fig. 17. A typical characteristic curve (A) showing how the grid voltage (B) and the plate current (C) vary on it.

Now let us see how different values of grid bias affect the way in which a tube amplifies a signal. As you know, the grid voltage is made up of a fixed bias voltage, and the ac signal is superimposed on it. Assume we have a tube with the E_g-I_p curve shown in Fig. 17A. The center of the linear part of the curve is at -3 volts. Now suppose we have a bias voltage of -3 volts, and the signal voltage shown in Fig. 17B, which varies from 0 to 3 volts, is superimposed on it. When the ac signal is at the start of its cycle, point 1, it will be zero, so the total grid voltage will be -3, point 1 on the curve in 17A. When it increases to point 2, the total voltage will then be zero, point 2 on the curve. At point 3 the total voltage will be -3 volts again. At point 4 the total voltage will be -6, and at point 5 the total voltage will again be -3.

Now let's draw ourselves a picture showing what is happening to the plate current at each of these points. At point 1 the current is 4.5 ma; at point 2 it is 8 ma; at point 3 it is again 4.5 ma; at point 4 it is 1 ma; and at point 5 it is 4.5 ma again. This is shown in Fig. 17C.

As you can see, this is a faithful reproduction of the applied signal.

We often show these things all on one chart as shown in Fig. 18. Notice how we have drawn the signal voltage. By drawing it in this position, we can follow up to the point it represents on the characteristic curve, and then show the curve for the corresponding plate current.

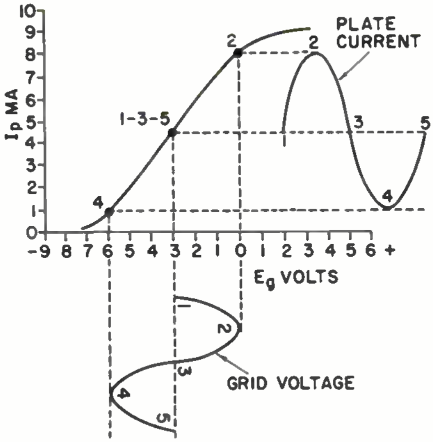

Fig. 18. We often show the information of Fig. 17. all on one diagram like this.

In Fig. 19 we have shown what happens when the operating bias is too high or too low. In Fig. 19A the operating bias is too high (too negative) and the result is that the grid is driven beyond the cut-off voltage

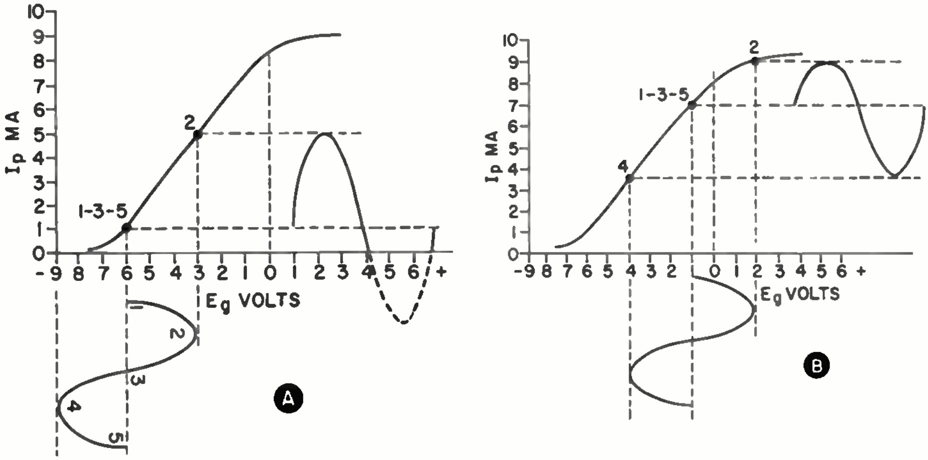

Fig. 19. The effect of too much bias is shown at A, and the effect of too little bias at B.

on the negative half of each cycle. This means that the plate current drops to zero and flattens off on the negative half of each cycle.

In Fig. 19B the operating voltage is not high enough, so during part of each cycle the grid becomes positive. When this happens the grid will start to take some of the electrons that would normally flow to the plate of the tube with the result that the top of the plate current curve is somewhat distorted. The variations in plate current for a given input signal are not linear when the bias is too low.

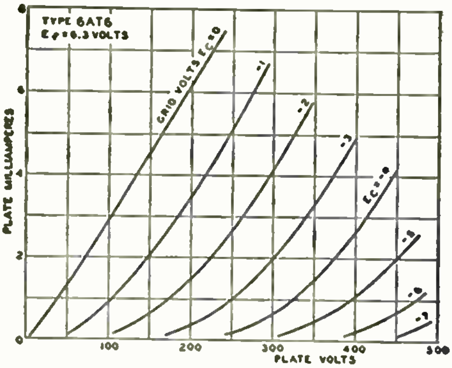

Fig. 20. E_p-I_p curves of the 6AT6 tube.

THE Ep-Ip CURVE

The characteristic curves shown in a tube manual are usually E_p-I_p (plate voltage-plate current) curves such as those shown in Fig. 20. Each curve is for a particular value of grid voltage. As you can see, when the plate voltage is higher it takes a higher grid bias voltage to cut off the flow of plate current. You can also get a good idea of how a change in grid voltage affects the plate current. Find the vertical line representing a plate voltage of 200 volts. Follow this line up until you see where it cuts the curve representing zero grid volts. It cuts this line just above the horizontal line representing a plate current of 6 ma. The -1 volt grid curve cuts the 200 volt line at about 3.5 ma. Thus, changing the grid voltage from zero to -1 volt will change the plate current from above 6 ma to 3.5 ma, or about 2.5 ma.

Notice how much more effective the grid is in controlling plate current than the plate is. We saw that a change in grid voltage of 1 volt caused a plate current change of 2.5 ma. The -1 volt grid curve cuts the 200 volt line at 3.5 ma. If we increase the plate voltage to 250 volts and keep the grid bias at -1 volt, the plate current will be 5 ma, which is a change of only 1.5 ma from the 200-volt point. Thus the change in plate voltage of 50 volts has less effect on the plate current than a change of grid voltage of only 1 volt.

PLATE RESISTANCE

As we mentioned previously, a tube has internal resistance. The tube, in amplifying a signal, acts very much like a generator with an internal resistance. This internal resistance of the tube is called the ac plate resistance. Because the tube has this internal plate resistance, the gain that can be obtained from a tube is never quite equal to the amplification factor of the tube.

The ac plate resistance is defined as the ratio of the change in plate volts to the change in plate current that it produces. The symbol r_p is usually used to represent the ac plate resistance of the tube. The symbol e_p is used to represent the change in plate voltage and the symbol i_p is used to represent the change in plate current. Thus the plate resistance of a tube in ohms is:

$$r_p = \frac{e_p}{i_p}$$

The ac plate resistance is one of the characteristics listed in manufacturers' tube manuals. When the tube manual gives a plate resistance, it is for a certain value of plate and grid voltage. The ac plate resistance of a tube is affected by the dc voltage applied to the plate and by the dc voltage applied to the grid. Therefore, if the tube is operated at voltages other than those listed, the plate resistance will not be the same as the values shown. In some engineering type tube manuals the plate resistance is given in the form of a curve so that the plate resistance can be determined with different values of plate and/or grid voltages.

So far we have been talking about the ac plate resistance of a tube. However, a tube also has a dc resistance. In a circuit such as the one shown in Fig. 13, with no input signal applied to the grid, a certain value of plate current will flow. This plate current produces a voltage drop across the tube and a voltage across the load resistor. You know from Ohm's Law that the resistance is equal to the voltage divided by the current, thus the dc resistance of the tube is equal to the dc plate voltage, which is the voltage between the plate and cathode of the tube divided by the dc plate current. Notice that both of these values are dc values and therefore we get a dc plate resistance for the tube. This particular characteristic is not usually of importance and when we refer to the plate resistance of the tube we will always mean the ac plate resistance unless we specifically say that we are referring to the dc plate resistance.

MUTUAL CONDUCTANCE

Another important tube characteristic is mutual conductance. The mutual conductance of the tube is usually represented by the symbol g_m. It is equal to the change in plate current divided by the change in grid voltage required to produce the change in plate current. The unit of mutual conductance is the mho. Notice that mho is simply ohm written backwards.

The formula for the mutual conductance of a tube is:

$$g_m = \frac{i_p}{e_g}$$

where g_m is the mutual conductance, i_p is the change in plate current and e_g is the change in grid voltage.

Since the change in plate current is usually in milliamperes, and the change in grid volts is in volts, the mutual conductance of the tube turns out to be a fraction of a mho. For example, if a change in grid voltage of 1 volt produces a change in plate current of 1 milliampere, the mutual conductance is:

$$g_m = \frac{.001}{1} = .001 \text{ mho}$$

To eliminate the fraction we usually express the mutual conductance of a tube in micromhos. A micromho is a millionth of a mho. Thus .001 mho equals 1000 micromhos.

RELATIONSHIP BETWEEN TUBE CHARACTERISTICS

So far we have discussed three important tube characteristics. They are the amplification factor, the plate resistance, and the mutual conductance. They can be represented by symbols as follows:

$$\text{Amplification factor} = \mu = \frac{e_p}{e_g}$$

$$\text{Plate resistance} = r_p = \frac{e_p}{i_p}$$

$$\text{Mutual Conductance} = g_m = \frac{i_p}{e_g}$$

Now let us look at how these characteristics are inter-related. If we multiply the plate resistance by the mutual conductance we get:

$$r_p \times g_m = \frac{e_p}{i_p} \times \frac{i_p}{e_g}$$

If you look at the second expression you will see that you have i_p both above and below the line so these two can be cancelled and we get:

$$\frac{e_p}{e_g}$$

We already know that e_p over e_g equals μ, which is the amplification factor. Thus the amplification factor is equal to the plate resistance times the mutual conductance or:

$$\mu = r_p \times g_m$$

EQUIVALENT CIRCUITS

It is sometimes difficult to visualize exactly what is happening inside a tube and in the circuit associated with the tube. However, by means of what is called an equivalent circuit we can analyze the performance of a tube more easily. A typical triode amplifier is shown in Fig. 21A and the equivalent circuit for this stage is shown in Fig. 21B. Notice that the tube is represented by a generator with a resistance connected in series with it. The voltage developed by the tube is equal to the amplification factor of the tube times the grid voltage which is written μe_g. We know, however, that the output voltage will be 180 degrees out of phase with the input, and we therefore put the minus sign in front of μe_g and indicate that the generator voltage is $-\mu e_g$. This indicates that the generator voltage, which is the amplified voltage produced by the tube, is 180 degrees out of phase with the grid voltage. In other words, at the instant the grid voltage swings positive, the generator will swing negative and then when the grid voltage swings negative, the generator voltage swings positive.

The ac plate resistance of the tube is represented by the resistor r_p. The voltage dropped across this resistance is lost as far as obtaining useful output is concerned.

Now let us see just exactly how

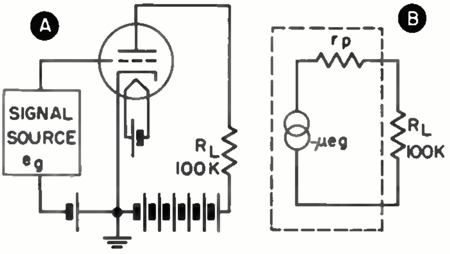

Fig. 21. A simple amplifier circuit is shown at A, and the equivalent circuit at B.

much gain we can obtain from the circuit shown in Fig. 21A. We could find the plate resistance of the tube and the amplification factor by looking them up in a tube manual. Let's assume that the amplification factor of the tube used in the circuit is 100, and the plate resistance of the tube is 50,000 ohms. The load resistance R_L is 100K ohms as shown on each diagram.

If the input signal e_g had an amplitude of 1 volt, then the generator output voltage $\mu e_g = 100 \times 1 = 100$ volts. The 100 volts produced by the generator divides between the 50,000-ohm plate resistance r_p and the 100,000 ohm load resistance, R_L. Thus, since the load resistance is twice the size of the plate resistance, the voltage across the load resistance will be twice the voltage across the plate resistance. This means that one-third of the 100 volts at the generator will appear across the plate resistance, and two-thirds, or approximately 66 volts, will appear across the load resistance. From this we can see that for an input voltage of 1 volt, the useful output voltage across the load resistor is 66 volts. The gain of the stage is equal to the output voltage divided by the input voltage, which in this case is $66 \div 1 = 66$. Therefore in this circuit using a tube with an amplification factor of 100, we obtained a gain of 66.

Consider what would happen if instead of using a 100,000-ohm plate load resistor we used a 200,000-ohm plate load resistor. Now the plate load resistor is four times the plate resistance and therefore there will be four times as much voltage across the load resistor as across the plate resistance. This means that one-fifth of the voltage, or 20 volts, will appear across the plate resistance, and four-fifths, or 80 volts, will appear across the load resistor. Therefore, the output voltage in this case would be 80 volts and the gain of the stage would be 80.

From this you might think that all we have to do is make the plate load resistor very large and we would get even more gain. This is true up to a point, but remember that the current flowing in the plate-cathode circuit of the tube must also flow through the plate load resistor. The current through the plate load resistor produces a voltage drop across the load resistor. The higher the resistance of the resistor the greater the voltage drop across it. Since the voltage available between the plate and the cathode of the tube is equal to the B supply voltage minus the voltage drop across the plate load resistor there will be very little voltage available between the plate and cathode of the tube if we make the plate load resistor too large. Eventually a point is reached where the plate-cathode voltage is so low that the amplification factor of the tube begins to fall off. When this point is reached, increasing the size of the plate load resistor results in no further increase in the gain of the stage.

A way to calculate the gain of a triode stage is by the equation:

$$\text{Stage gain} = \mu \times \frac{R_L}{R_L + r_p}$$

This equation shows that the larger the value of R_L with respect to r_p, the greater the gain of the stage. However, as we pointed out there are practical limits to this because the plate voltage does drop too low if R_L is made too large.

SUMMARY

In this section of this lesson you have greatly expanded your knowledge of tubes. There is a great deal of information in the section, and you should not expect to master and retain all the ideas presented with one reading. Be sure to go back and review this section of this lesson several times. This is particularly important because practically all of your later lessons are going to be based on the assumption that you understand how tubes work.

Characteristic curves are important because they give you an indication of how the plate current of a tube is going to change with changes in grid voltage. You can also see how large a signal a tube can handle without distortion. We do not expect you to remember what the characteristic curves we show look like, but you should remember that they are curved on both ends and this curvature in the characteristic curve limits the amount of signal that can be handled without distortion.

The three characteristics of tubes that you should remember are the plate resistance, the amplification factor, and the mutual conductance. Remember what they are:

$$\text{Plate resistance} = r_p = \frac{e_p}{i_p}$$

$$\text{Amplification factor} = \mu = \frac{e_p}{e_g}$$

$$\text{Mutual conductance} = g_m = \frac{i_p}{e_g}$$

You should also remember that the amplification factor of a tube is equal to the plate resistance times the mutual conductance.

Remember what the equivalent circuit of the simple triode amplifier looks like. We consider the tube as a generator with a resistance in series with it. The output voltage of the generator is equal to $-\mu e_g$. The resistance in series with the generator is equal to r_p, the plate resistance of the tube.

Remember that the equivalent tube circuit applies only to the ac signal-amplifying operation of the tube. We did not discuss the dc operating voltages when we discussed the equivalent circuit. Later you will see that the equivalent circuit is very valuable in analyzing and understanding the operation of amplifier stages. It will be particularly useful when we study how amplifiers amplify signals of different frequencies.

SELF-TEST QUESTIONS

(x) What is an E_g-I_p curve?
(y) What do we mean by the linear portion of the E_g-I_p characteristic curve?
(z) What is a grid bias voltage?
(aa) What will be the effect of operating the tube with too low a grid bias?
(ab) What happens when a tube is operated with too high a grid bias?
(ac) What is an E_p-I_p curve?
(ad) What is the ac plate resistance of a tube?
(ae) What is the dc plate resistance of a tube?
(af) What is the mutual conductance of a tube?
(ag) In what units is the mutual conductance of a tube measured?
(ah) What is the relationship between amplification factor, plate resistance and mutual conductance?

(ai) What do we mean by an equivalent circuit of an amplifier stage?

(aj) In an equivalent circuit used to analyze the performance of a triode amplifier, what is the generator voltage?

(ak) In the equivalent circuit of a triode amplifier, what is the resistance in series with the generator?

(al) If a triode amplifier has an amplification factor of 50 and a plate resistance of 10,000 ohms, what will the stage gain be when the amplifier is used in a circuit with a 90,000-ohm load resistor?

Multi-Element Tubes

From your study of the preceding section you can see that the triode tube is a very useful device. However, the triode has some definite limitations, and these limitations can be overcome by adding additional elements to the tubes. First, before studying the multi-element tubes, let's consider one of the big disadvantages of the triode in order to be able to understand the advantages of multi-element tubes better.

PLATE-TO-GRID CAPACITY

You will remember from your lesson on capacitors that a capacitor consists of two metal plates placed close to each other. In capacitors the metal plates are deliberately placed near each other in order to have capacity. However, when two pieces of metal that are insulated from each other are brought near each other, we will have a capacitor whether we want it or not; for example, the plate and grid of a vacuum tube. The plate, as you know, consists of a cylindrically shaped piece of metal. The grid is a spiral wire or mesh. The grid and plate, since they are placed near and are insulated from each other, actually form the two plates of a capacitor. Because the grid wire is small and there is a reasonable amount of space between the plate and grid, the capacity is small, but in some circuits, particularly where fairly high frequencies are involved, there is a high enough capacity to introduce a number of undesired effects.

As you know, at a high frequency even a small capacitor has a fairly low reactance. Therefore if a triode tube is used to amplify a high-frequency signal, the amplified signal present in the plate circuit of the tube can be fed back into the grid circuit through the plate-to-grid capacity. Under certain circumstances this signal fed from the plate back to the grid can be in phase with the signal applied to the grid of the tube so it will add to the input signal. This increase in the amplitude of the input signal in turn produces a still greater signal in the output.

The increased signal in the output in turn increases the signal fed back into the grid circuit which makes the grid signal still stronger. This increases the output signal still more. This action goes on and on until eventually a point is reached where the signal in the plate circuit takes control in the grid and the tube begins to generate its own signal voltage. This is called oscillation. The signal fed from the plate of the tube back to the grid is called a feedback signal. When the feedback signal, or more simply the feedback, is of the correct phase so that it adds to the grid signal, the tube will oscillate, which means generate its own signal, and hence will not work as an amplifier.

Not all triode amplifier stages will oscillate. It is possible to overcome this problem by means of suitable circuitry. However, in most applications it is easier and more practical to overcome the problem in the tube itself. This is accomplished by the addition of another grid inside the tube. The second grid is placed between the plate and the first grid to shield or screen the grid from the plate and is called the screen grid or simply the screen. The screen is also called the number-two grid.

THE SCREEN-GRID TUBE

The screen-grid tube is a four-element tube usually called a tetrode. The four elements are the cathode, the grid, the screen grid, and the plate. A top view of a screen-grid tube showing the four elements is shown in Fig. 22A, and the schematic symbol for the screen-grid tube is shown in Fig. 22B.

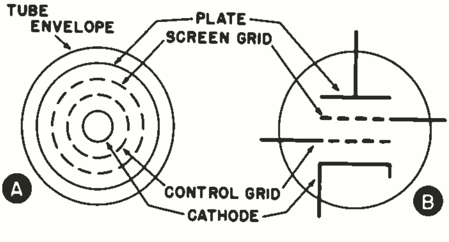

Fig. 22. A screen-grid tube: A, a cross section showing the arrangement of the elements; B, the schematic symbol.

The screen grid is usually made just like a spiral-wound coil. The screen-grid wires are placed directly behind the grid wires so they are completely hidden from the electrons by the grid wire. A cut-away view of the tube would look something like Fig. 23. Notice that the screen-grid wires are immediately behind the control-grid wires.

The effect of the screen grid is to break the capacity between the plate and the control grid into two separate capacitors. In other words, there is a small capacity between the plate of the tube and the screen, and another capacity between the screen of the tube and the grid. These two capacitors are connected in series so that the net plate-to-grid

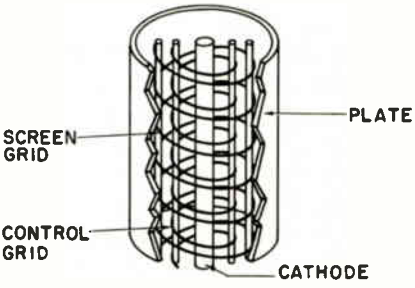

Fig. 23. A cut-away view of a screen-grid tube.

capacity is much smaller than it is in the triode. In addition, the screen grid of a tube is normally operated at signal ground potential. Therefore any energy fed from the plate of the tube back towards the grid is fed to ground at the screen. This practically eliminates the feedback from the plate to the grid of the tube.

The dc potential applied to the screen is always positive with respect to the cathode. Usually the voltage placed on the screen grid is about half the voltage applied to the plate of the tube, but in some tubes the screen-grid voltage may be as high as the plate voltage. This may appear to be a contradiction because we said that the screen grid is operated at the signal ground potential. Actually, it is possible to have a tube element at signal ground potential and still have a positive or negative dc voltage applied to it. You will remember that a capacitor offers a low reactance to the flow of ac through it. Therefore we can ground the screen of a tube so far as signal is concerned by putting a capacitor between the screen of the tube and ground. If the capacitor is large enough, its reactance to the signal is so low that the screen is practically at signal ground potential. At the same time, since a capacitor does not permit the flow of dc through it, you can connect it to a dc voltage source and apply a positive voltage to the screen.

The schematic diagram of a typical screen-grid amplifier circuit is shown in Fig. 24. Here the input signal is fed between the grid and the cathode of the tube as in the case of the triode. Electrons flow from the cathode of the tube to the plate of the tube as in the triode. However, in the tetrode tube the number of electrons flowing will depend upon the plate voltage, the grid voltage and the screen-grid voltage. In fact, the number of electrons flowing from the cathode towards the plate will depend much more on the screen and grid voltages than on the plate voltage.

As in the triode tube, small changes in grid voltage produced by the ac signal applied to the input will produce comparatively large changes in plate current. These changes in plate current will cause the voltage between the plate and cathode of the tube to vary, and this voltage will be the amplified output signal.

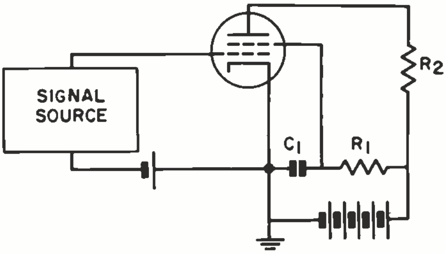

Fig. 24. Schematic of a screen-grid amplifier. R1 is used to reduce the B supply voltage for the screen, and is called the screen voltage dropping resistor, or simply the screen dropping resistor. C1 is the screen by-pass capacitor. R2 is the plate load resistor. The heater of the tube has been omitted to simplify the diagram.

A few of the electrons flowing from the cathode of the tube towards the plate of the tube will strike the screen. Thus there will be a small current flowing from the cathode of the tube, to the screen grid, through the power supply and back to the cathode.

Because the plate voltage has

much less effect on the plate current in a screen-grid tube than in a triode tube, screen-grid tubes have a much higher amplification factor than triodes. In addition they have a much higher plate resistance.

Disadvantages.

Although the tetrode is a great improvement over the triode, it does have certain disadvantages. One of these disadvantages, which led to the development of the pentode or five-element tube, occurs because of secondary emission.

As you already know, electrons travelling from the cathode of the tube to the plate reach a fairly high speed, and when they strike the plate they may knock other electrons off the plate. In a diode and a triode the plate is the only positive element in the vicinity of these loose electrons, and therefore they are attracted back to the plate. However, in a tetrode we have, in addition to the plate, the screen grid with a positive voltage applied to it. If the plate voltage is substantially higher than the screen voltage, the electrons will be attracted back to the plate, but if the screen voltage is almost equal to or even higher than the plate voltage, then the electrons knocked off the plate of the tube will be attracted to the screen instead of to the plate. Thus, for every electron reaching the plate from the cathode there may be two or three electrons emitted by the plate. This means that if the grid swings in a positive direction more electrons will strike the plate, knocking still more electrons off the plate. The net result can be that the plate current decreases when the grid swings positive. To prevent this undesirable action a third grid called a suppressor grid was added to develop the pentode tube.

PENTODE TUBES

The pentode tube is a tube with five elements. It is simply a refinement of the screen-grid tube, which is made by adding an additional grid between the screen grid and the plate of the tube. Thus, the pentode has three grids. The third grid, or suppressor grid, gets its name because it is put in the tube to suppress or eliminate the undesirable effects of secondary emission occurring at the plate of the tetrode tube. Because it is also the third grid it is sometimes called the number-three grid.

The suppressor is usually connected directly to the cathode of the tube, but sometimes it is connected directly to ground. It has very little effect upon the electrons travelling from the cathode of the tube towards the plate. These electrons are attracted from the cathode by the positive potential on the screen of the tube. They are accelerated by this voltage, but as they approach the screen, instead of stopping at the screen they pass right through the screen wires. Once they get through these wires they are attracted to the plate by its positive voltage, which is usually higher than the voltage on the screen. In the pentode tube, after the electrons have passed the screen they are moving at a fairly high velocity, and they travel right on through the suppressor grid to the plate. The suppressor does not have any appreciable effect on the progress of the electron as it moves from the cathode toward the plate.

When the electrons strike the plate they knock other electrons off the plate, as in the case of the screen-grid tube. However, these electrons are travelling at a comparatively low speed when they are knocked off the plate. The suppressor, which is connected to the cathode or to ground or may be operated with a low negative voltage applied to it, repels the electrons emitted from the plate by secondary emission, and these electrons move back to the plate of the tube. Thus, the addition of the suppressor grid eliminates the undesirable current flow from the plate of the tube to the screen grid, which we found could occur in the tetrode tube.

Because the pentode tube has a screen grid, it has the low plate-to-grid capacity that we found in the tetrode tube. In addition, the pentode has the advantage that it does not suffer from the adverse effects of secondary emission.

It might be well to point out now that the plate voltage on a tetrode or a pentode tube has very little effect on the plate current. The voltage on these tubes can be varied over wide limits without appreciably changing the plate current that will flow in the tube. For a given grid voltage, the plate current will depend primarily upon the screen voltage. The screen is the electrode that starts the electrons moving from the cathode to the plate and has more effect on the number of electrons that will flow from the cathode to the plate than the plate voltage does.

You will remember that one of the characteristics of vacuum tubes that we studied was the amplification factor. The amplification factor is the ratio of the plate voltage required to produce a given change in plate current to the grid voltage required to produce the same change in plate current. Remember that the formula is:

$$\mu = \frac{e_p}{e_g}$$

Since the plate voltage has very little effect on the plate current in a tetrode or pentode tube, it takes a very large change in plate voltage to produce the same change in plate current that can be produced by a small change in grid voltage. Thus, the amplification factor of a tetrode or a pentode tube is very high. We mentioned that the amplification factor of a triode may be somewhere between about 5 and 100. A triode with an amplification factor of 100 is called a high-mu triode because it has a high amplification factor for a triode. However, pentodes with amplification factors of over 1000 are common.

BEAM POWER TUBES

Another tube that solves the problem of secondary emission in screen-grid tubes is the beam power tube. The beam power tube, like the screen-grid tube, is a tetrode or four-element tube in which this problem has been overcome. A sketch of a beam power tube is shown in Fig. 25.

Notice the shape of the cathode of the tube. It has two flat surfaces. The construction of the cathode is such that most of the electrons will be emitted by the flat surfaces and hence there is a tendency for the electrons to form into two beams, one on each side of the cathode. Only one of these beams is shown in the drawing.

Notice the two small additional plates between the screen grid and the plate of the tube. These plates are called the beam-confining or

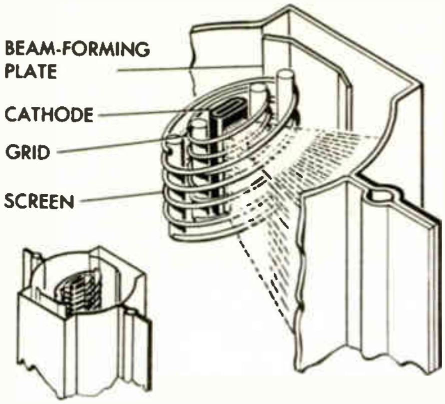

Fig. 25. A beam-power tube.

beam-forming plates. The beam-forming plates are connected internally to the cathode of the tube and repel electrons. These plates act to keep the electrons concentrated into the two beams that are formed at the cathode. The electrons flowing from the cathode of the tube towards the plate are bunched together in these beams.

You will remember that an electron has a negative charge and will repel other electrons. Therefore, if an electron travelling at a high speed from the cathode of the tube to the plate knocks additional electrons off the plate, these loose electrons, which will be travelling at a low speed, will be repelled back to the plate by the negative charge on the electron beam.

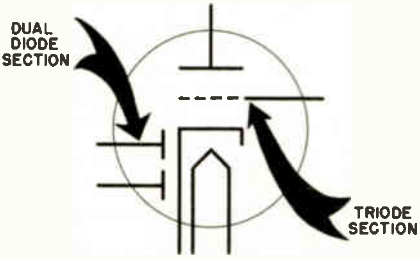

Fig. 26. A combination tube containing two diodes and a triode. This is called a duo-diode triode.

Beam power tubes are used in radio, TV, and industrial electronic equipment. Also, large beam power tubes are used in transmitters. The beam power tube has proven superior to the pentode in applications where large amounts of power must be handled.

OTHER TUBE TYPES

The diode, triode, tetrode, and pentode are the basic tube types. However, there are many special tubes that have been manufactured for special applications. In addition, there are tubes that are simply combinations of several tubes in the same envelope.

An example of a tube where several types have been combined in one envelope is the tube with a triode and two diodes in it. A schematic of this type of tube is shown in Fig. 26. This tube is called a duo-diode-triode. As this name indicates, it has two diodes and a triode in one envelope.

Other tubes consist of two triodes in one envelope such as shown in Fig. 27. In the schematic shown at A, a common cathode is used for the two triode sections; in the one shown at B, each triode section has its own separate cathode.

Another combination type is the triode-pentode shown in Fig. 28. This type of tube is used in radio, TV, and many industrial applications. In this way, one tube can be made to do the work of several.

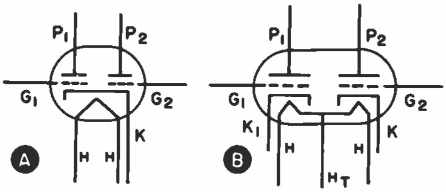

Fig. 27. Dual triode tubes. The tube at A has a common cathode. The tube at B has two separate cathodes. Notice this tube has a single heater with a center tap. Not all tubes of this type have tapped heaters.

The pentagrid tube, shown in Fig. 29, is an interesting tube. It is called a pentagrid tube because it has five grids. Tubes of this type are used as combination mixer-oscillators in radio and TV receivers. We will study this type in more detail later.

You will also run into a tube called the Compactron. The Compactron is simply a tube where several types are combined in one envelope. Compactron tubes have a base with twelve pins so it is possible to put a number of tubes in the same envelope. Some Compactrons may have three triodes in the one envelope; some may have two pentodes in the same envelope. Others are combinations of diodes, pentodes and triodes. Tubes such as Compactrons offer an advantage over tubes in separate envelopes inasmuch as they are somewhat less expensive to manufacture than separate tubes, and also it is possible to make more compact equipment because the space occupied by the multi-function tube is considerably smaller than the space that would be required for separate tubes.

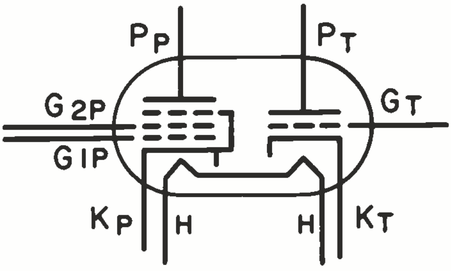

Fig. 28. A pentode-triode.

The Nuvistor tube is another important tube. Most Nuvistors are simply triode tubes but they are very small tubes. They look almost like a flat thimble. The advantage of the Nuvistor tube, in addition to its small size, is the very low capacity between the elements and the comparatively high gain that can be obtained with this type of tube. Because of the very small size of the elements used in the Nuvistor tube, this tube is quite widely used as an rf amplifier in TV receivers. Later, when we start studying specific amplifier circuits, you will see why such a tube as the Nuvistor would be advantageous as an amplifier at very high frequencies.

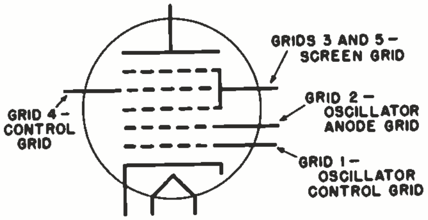

Fig. 29. A pentagrid tube.

While not all Nuvistor-type tubes are triodes, almost all the ones you are likely to encounter will be triodes. There have been a few tetrode Nuvistors manufactured, but these were primarily for industrial applications rather than entertainment-type equipment. In addition, due to manufacturing difficulties and competition from transistors, Nuvistors other than the triode types have not been too widely used.

CHARACTERISTIC CURVES

The characteristic curves for pentode tubes are quite different from those for triodes. The E_p-I_p curves for a typical pentode tube are shown in Fig. 30. Notice that the curves bend rather sharply at the left, but then are quite flat. For example, notice the curve representing the plate current with a grid bias of -2 volts. As we start at the lower left of the graph this curve rises rapidly until we reach the line representing the plate voltage of 50 volts. At this point the plate current is almost 2 milliamperes. Then, if the voltage on the plate of the tube is increased from 50 volts on up to 450 volts, there is very little change in the plate current. This simply demonstrates what we mentioned previously; in a pentode tube the plate voltage has very little effect on the current-the plate current is primarily determined by the grid voltage and the screen voltage.

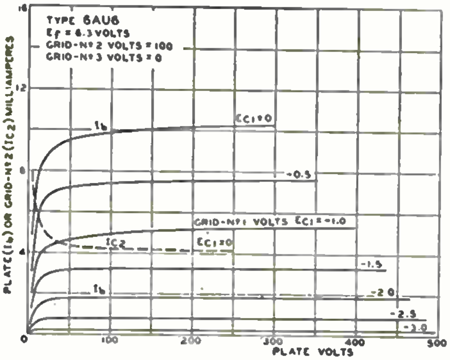

Fig. 30. E_p-I_p curves for the 6AU6 tube.

The characteristic curves for beam power tubes are quite similar to those for pentode tubes. We have not shown curves for screen-grid tubes, because the screen-grid tube has been replaced by the pentode and beam power tubes in modern design.

SUMMARY

In this section of the lesson you have studied multi-element tubes. Remember that the screen-grid tube was developed to eliminate the undesirable effects produced by the high plate-to-grid capacity found in triode tubes. A screen-grid tube is a tube with a high amplification factor and low plate-to-grid capacity. However, because the screen is operated with a positive voltage, the electrons emitted from the plate by secondary emission were attracted both to the plate and to the screen of the tube. Some of the electrons would flow to the screen and introduce a number of undesirable effects.

To overcome the problem created by secondary emission in the screen grid tube, the pentode or five-element tube was developed. The pentode contains three grids: a control grid, a screen grid, and a suppressor grid. These grids are often referred to as grids 1, 2, and 3.

The undesirable effects of secondary emission can also be overcome by constructing a flat type of cathode and using beam-forming plates. This led to the development of the beam power tube. The beam power tube is a tetrode tube, but it differs substantially in performance and construction from the old screen-grid tube.

In addition to the screen grid, pentode, and beam power tubes, there are a number of special tubes. These tubes may actually be tubes designed for one specific application such as the pentagrid converter type tube, or may simply be two or three different tubes combined in the one envelope. Tubes of this type consist of twin triodes, triode-pentode combinations, and duo-diode-triodes.

SELF-TEST QUESTIONS

(am) What is the purpose of the screen grid in a tetrode tube?

(an) What dc operating potential is applied to the screen of a tube?

(ao) How is the screen of a tetrode tube operated in order to provide maximum shielding between plate and grid?

(ap) Name the five elements in a pentode tube.

(aq) What elements control the flow of plate current in the pentode tube?

(ar) How are the undesirable effects of secondary emission overcome in the beam power tube?

(as) What is a Compactron?

(at) What is a Nuvistor?

Special Tube Types

There are a number of special-purpose tubes that have been designed for particular applications. Many of these tubes were designed for use in transmitting and industrial electronic equipment, but some of these tubes will also be found in equipment that the radio-TV serviceman may be called on to service. In most cases it is not particularly difficult to understand how these tubes operate.

GAS-FILLED DIODES

We mentioned earlier that gas is sometimes deliberately introduced into a tube. A common application of this principle is found in some diodes where mercury is placed inside the tube. The mercury vaporizes, filling the inside of the tube with mercury vapor. This particular type of tube makes an excellent rectifier. One of its characteristics is that the voltage drop across the tube is almost constant regardless of the current flowing through the tube. Let us look into the mercury-vapor diode tube and see how it differs from a high-vacuum diode.

The circuit shown in Fig. 31 can be used to compare the characteristics of the vacuum diode and the mercury-vapor diode. If we use a vacuum diode in this circuit, we will find that when the voltage applied to the circuit is zero, the voltage between the plate and the filament of the tube is zero, and the current flowing in the circuit is zero. If we increase the voltage to 5 volts, we

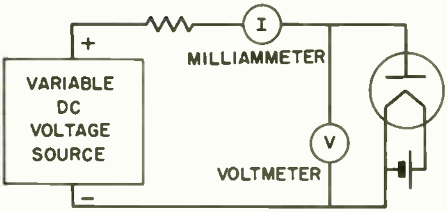

Fig. 31. A circuit for comparing vacuum and gas-filled diodes.

will notice a reading on the voltmeter indicating that there is voltage between the plate and the filament of the tube and that current is starting to flow in the circuit. If we then increase the variable voltage source to 10 volts, we will find that the voltage between the plate and the filament of the tube has increased and that the current flowing in the circuit has increased. If we keep increasing the voltage in 5-volt steps, we will find that the reading on the voltmeter will gradually increase, and at the same time the current flowing in the circuit will increase. This will continue in this way until a plate voltage is reached where all the electrons being emitted by the tube are being attracted to the plate. Then, increasing the voltage would result in little or no increase in current flowing through the tube. If we plotted the curve to show the relationship between the voltage across the tube and the current flowing through the tube, we would get a curve like the one shown in Fig. 32A.

If we perform the same experiment with a mercury vapor diode, we would obtain somewhat different results. If we started with the voltage from the variable voltage source at zero, we would find the reading on the voltmeter connected between the plate and filament of the tube was zero and again that the current flowing in the circuit was zero. When we increase the source voltage until we get a reading on the voltmeter of about 5 volts, there will be a current flowing in the circuit. A further increase to 10 volts would result in a further increase in the current flowing in the circuit. If we increase the voltage to 15 volts, we would get another increase in the current flowing in the circuit. However, when we increase the voltage above 15 volts something unusual will happen. At some voltage above 15 volts, the tube will fire; this means that it will suddenly start to glow with a blue glow. When this happens, the reading on the voltmeter connected between the plate and the filament of the tube will drop back to 15 volts. We would find that increasing the voltage from the variable voltage source further would not result in any increase in the voltage between the plate and the filament of the tube. However, the current flowing in the circuit would continue to increase as long as we increased the voltage of the source. If we plotted a curve to show the relationship between the voltmeter reading and the milliammeter readings for this tube, we

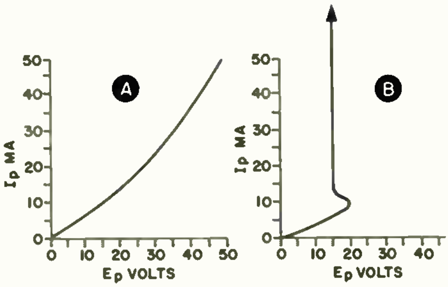

Fig. 32. The E_p-I_p curve for a vacuum diode is shown at A, and the curve for a mercury-vapor diode is shown at B.

would get a curve similar to Fig. 32B. Notice that up to some voltage slightly over 15 volts this curve is very similar to the curve obtained for the vacuum diode, but when the firing point is reached, the voltage between the plate and the filament of the tube drops down to 15 volts and then remains constant at this value, while at the same time the current through the tube can increase almost indefinitely.

Now let us see what is happening inside the mercury vapor tube. When the low positive voltage is applied to the plate of the tube, electrons emitted by the filament are attracted to the plate. These electrons do not reach any great velocity, so they simply travel over to the plate of the tube. Some of them will strike the gas molecules inside the tube, but they are not traveling at a high enough speed to knock any electrons off the molecules. As the plate voltage is increased, eventually a voltage is reached where the electrons travelling from the filament to the plate of the tube reach a high enough speed to knock electrons off the gas molecules that they strike. When this happens, the electrons knocked off the gas molecules travel over to the plate of the tube, thus increasing the number of electrons reaching the plate. At the same time, the molecules that have had some electrons removed will have a positive charge on them, and they will travel over towards the filament of the tube. As these molecules enter into the area of the space charge around the tube filament, they will pick up electrons from the space charge, lose their positive charge, and then begin to drift away from the tube cathode. They, in turn, will be hit by other electrons travelling from the filament of the tube to the plate, which will knock electrons off the gas molecule again, give it a positive charge, and once more it will start back to the space charge to pick up additional electrons in order to get rid of the positive charge.

If the right amount of mercury vapor is present in the tube, the gas molecules will neutralize or eliminate the effects of the space charge around the filament of the tube. Thus, the electrons will be able to leave the filament and travel directly to the plate of the tube with little or no opposition. This results in a tube with a very low internal resistance. The voltage drop across a tube of this type is almost constant and is about 15 volts regardless of the current flowing through the tube.

When the gas inside the tube ionizes, it gives off a bright blue glow. When this happens we say that the tube fires. The firing point for a mercury vapor tube is slightly above 15 volts, but once the tube has fired the voltage drop across the tube will drop back to approximately 15 volts and remain essentially constant at this value.

Mercury vapor diodes are used as rectifiers. It is a great advantage to have rectifier tubes that have a constant voltage drop, particularly in equipment where the current drawn from the power supply varies appreciably. If the current varies and a vacuum type rectifier is used, there will be considerable variation in the voltage drop across the tube, and as a result a variation in the output voltage from the power supply. However, in a mercury vapor tube, since the voltage drop across the tube is practically constant regardless of the current flowing through it, the output voltage from

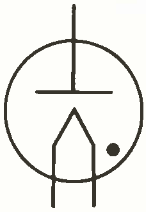

Fig. 33. Dot inside the envelope is used to indicate a gas-filled tube. This is the schematic symbol for a gas-filled diode.

the power supply will be almost constant even though the current drawn from the supply and through the tube may vary appreciably.

To distinguish tubes containing gas from vacuum tubes in a schematic diagram, a dot is usually placed inside the tube envelope on the schematic symbol. The schematic symbol for a gas-filled diode rectifier is shown in Fig. 33.

Mercury is not the only gas used in gas-filled tubes, but it is the most commonly used in rectifier tubes. Mercury-vapor tubes are not found in modern radio and TV receivers but are used in many other applications.

An example of another gas-filled diode is the Tungar tube. This tube is somewhat similar to and operates on the same principle as the mercury-vapor diode, but instead of mercury, argon gas is introduced into the tube. This tube has many of the characteristics of the mercury-vapor diode; it has an almost constant voltage drop of about 10 volts across it. It is particularly suitable for applications requiring a low voltage and a high current.

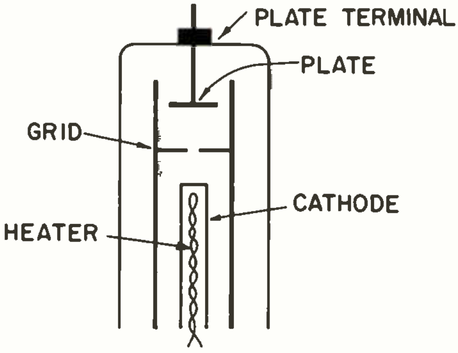

Fig. 34. Construction of a thyratron.

THE THYRATRON

In addition to mercury-vapor diodes, mercury-vapor triodes are also used. A mercury-vapor tube with a grid is called a thyratron. The construction of a thyratron is somewhat different from the construction of a vacuum-type triode tube. A sketch of a thyratron is shown in Fig. 34.

The control that the grid has over the flow of plate current in the thyratron is quite different from the control the grid has in the high-vacuum rectifier. In a thyratron, as long as the grid is maintained sufficiently negative to cut off the flow of plate current, there will be no electron flow from the cathode of the tube to the plate. Even with a high positive voltage on the plate of the tube, the grid, if it is negative enough, can block the flow of electrons to the plate. Electrons emitted by the cathode are simply driven back into the space charge and to the cathode.

Up to this point the action of the grid in a thyratron is similar to the action of the grid in a vacuum triode. However, if the grid voltage on the thyratron is reduced below the value required for cut-off, something entirely different happens.

A circuit using a thyratron is shown in Fig. 35A. If the grid is made negative and a positive voltage

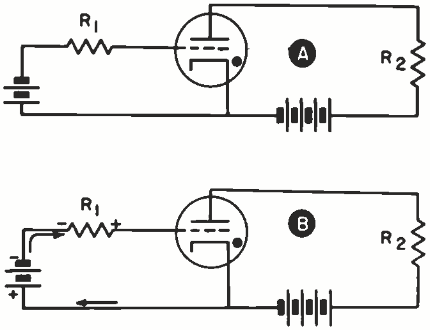

Fig. 35. Circuit using a thyratron.

is applied to the plate, the grid is able to cut off the flow of plate current. Once the grid voltage is reduced below cut-off, electrons begin flowing from the cathode of the tube to the plate. These electrons flowing through the tube will strike the gas molecules and knock electrons off them. These electrons will flow over to the plate of the tube. Meanwhile, the gas molecules that now have a positive charge on them will drift to the space charge to pick up electrons to neutralize the positive charge. In doing this, they remove the electrons in the space charge which in effect reduces the internal resistance of the tube, and permits a high current to flow.

If we try to cut off the flow of plate current by increasing the negative grid voltage to the cut off value again, the negative grid will attract positive ions which are gas molecules that have had electrons knocked off them. These positive ions will, in turn, attract electrons from the grid. These electrons are coming to the grid through R1, and as a result there will be a voltage drop across this resistor as shown in Fig. 35B. This voltage drop has a polarity opposite to that of the grid battery and will tend to neutralize the negative voltage applied in the grid circuit so the grid itself does not become very negative. Therefore, the grid is unable to gain control of the plate current, so the plate current continues to flow from the cathode to the plate of the tube even though the negative voltage applied to the grid circuit may be considerably greater than the applied voltage that would originally cut off the flow of plate current. If we increase the negative grid voltage to a very high value to try to cut off the flow of plate current, we simply attract more ions to the grid. These positive ions will attract more electrons from the grid, with the result that the number of electrons flowing from the grid to the ions may become quite high. This current could become so high the tube would be destroyed if it were not for the resistor R1 placed in the grid circuit which helps to keep the grid current down to a safe value.

In a thyratron, if the plate current is to be cut off by the grid voltage, the negative voltage needed to cut off the flow of plate current must be applied to the grid of the tube before the plate voltage is applied. Then the positive voltage can be applied to the plate of the tube, and the grid will prevent the electrons from reaching the plate of the tube. But once the grid voltage is reduced to a point called the "starting" point, where electrons can begin flowing from the cathode to the plate, the tube will fire, just as the mercury-vapor diode does, and the positively charged molecules will neutralize the space charge. This will permit a high current to flow through the tube and at the same time be attracted to the grid and neutralize any negative voltage placed on it to try to cut off the flow of plate current.

In a circuit using a thyratron, once the grid has lost control of the flow of plate current, the only way it can regain control is by removing the plate voltage from the tube. Once the plate voltage is removed, the grid can regain control; plate voltage can then be reapplied to the tube and no current will flow through it as long as the grid voltage is kept sufficiently negative to prevent any electrons from flowing from the cathode to the plate of the tube.

Thyratrons are extremely useful in industrial electronic applications. In some circuits, ac is applied to the plate of the tube instead of dc.

THE CATHODE-RAY TUBE

Another important tube found in many pieces of test equipment and also in TV receivers is the cathode ray tube. A photo of a cathode ray tube is shown in Fig. 36.

In the neck of a cathode ray tube is a device known as an electron gun. A typical electron gun is also shown in Fig. 36. The electron gun contains a heater, which heats a cathode; the cathode emits electrons; and these electrons are attracted by the high positive voltage on the anodes in the tube. Between the first anode and the cathode is the grid, as shown in the figure. The grid is used to control the number of electrons passing from the cathode towards the anodes.

The anodes in a cathode ray tube are arranged with a hole in the center of them so that instead of attracting electrons to themselves, they accelerate the electrons down the neck of the tube. The electrons pass right through the holes in the anodes and travel at a very high speed towards the face of the cathode ray tube. The face of the cathode ray tube is covered with a phosphorescent type of material. When this surface is struck by electrons, it glows and gives off light.

If the electrons accelerated down the electron gun were permitted to travel directly towards the face of the tube, they would all strike the face at approximately the same spot--somewhere near the center of the tube. However, the electron beam

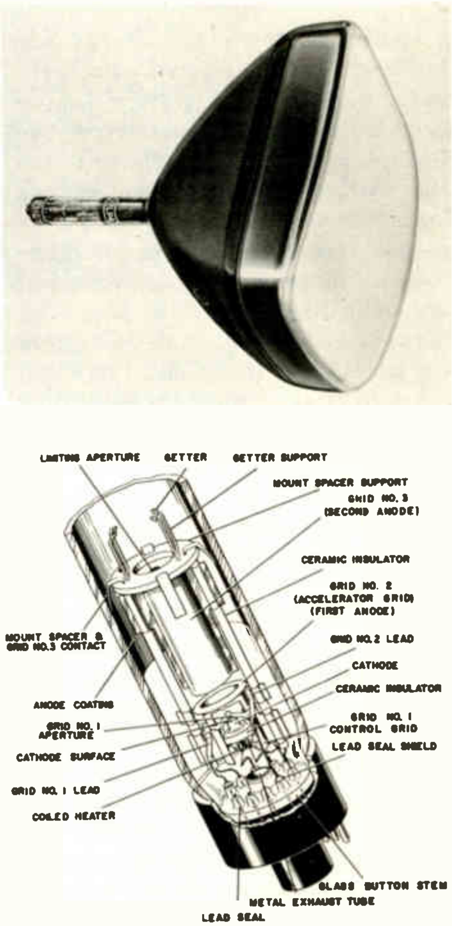

Fig. 36. A cathode ray tube is shown above; an electron gun of a crt below.

can be deflected so that it can be made to strike any point on the face of the tube.

The electron beam can be deflected by means of plates inside the neck of the cathode ray tube. If a positive voltage is put on one plate and a negative voltage on another, the positive plate will attract and bend the electron beam towards it and at the same time the negative plate will push the beam away from it. If two sets of parallel plates are installed in a tube, one in the horizontal plane and the other in the vertical plane, the horizontal plates can be used to move the electron beam up and down, and the plates installed in the vertical direction can be used to move the electron beam from side to side. Such a tube is called an electrostatic cathode ray tube.

The electron beam may also be deflected by magnetic fields produced by two pairs of coils. This is called electromagnetic deflection. The picture tubes used in TV receivers use this type of deflection.

Color picture tubes are similar to the tubes shown in Fig. 36 except that three electron guns are used inside of the tube. One gun is used for each of the three primary colors, red, blue and green. These guns are arranged to produce three electron beams that travel to the face of the picture tube and strike phosphors that will give off colored light. In other words, the blue gun strikes a phosphor dot that produces blue; the red gun strikes a phosphor dot that produces red, and the green gun strikes a phosphor dot that produces green. Hundreds of thousands of dots are placed on the face of the tube, and by sweeping the electron beams over the face of the tube it is possible to produce color pictures. Of course, the color tube is more complex than this, and there are other parts that we have omitted. We will study them later, but this will give you a general idea of what a color tube is like.

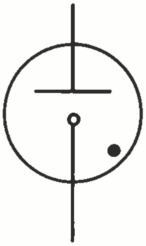

Fig. 37. Schematic symbol of a VR tube.

OTHER SPECIAL TUBE TYPES

There are many other special tube types found in electronic equipment.

Voltage Regulator Tubes.

One type that is quite common is the voltage regulator tube, often abbreviated the VR tube. The schematic symbol used to represent a VR tube is shown in Fig. 37.

Notice that the VR tube is a gas-filled tube. It is often used in a circuit like the one shown in Fig. 38. An important characteristic of this type of tube is that it maintains an almost constant voltage drop across it. If the voltage tends to increase, the tube will draw current, which will result in a greater voltage drop across the resistor so that the volt-

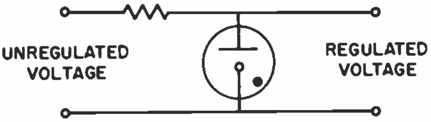

Fig. 38. A circuit using a VR tube.

age across the tube will remain constant. This type of tube is used to regulate the voltage in circuits where it is important for the voltage to be held as constant as possible.

Photo Tubes.

Another type of tube found in electronic equipment is the photo tube. This tube has a cathode and an anode, or plate. Instead of emitting electrons by thermionic emission, this tube is designed to emit electrons when light strikes its cathode. Electrons travel over to the plate of the tube and thus current flows through the tube. In Fig. 39 we have shown a picture of a photoelectric tube and the schematic symbol for it.

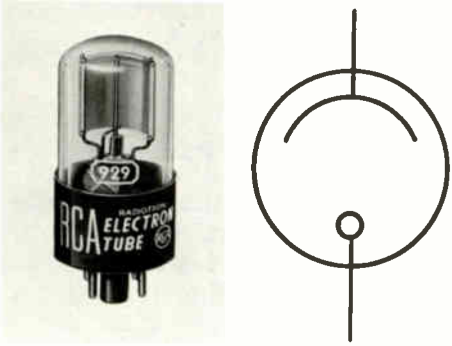

Fig. 39. A photoelectric tube and its schematic symbol.

SUMMARY

There are many special tube types in electronic equipment. Among these are the gas-filled tubes. Gas-filled diodes are frequently used in power supplies, particularly where the current drawn from the power supply goes through wide variations. Mercury-vapor rectifier tubes are found in many pieces of industrial electronic equipment and in the power supplies of most radio and TV transmitters.

A three-element mercury-vapor tube is called a thyratron tube. The most important characteristic of a thyratron is that the grid can prevent the flow of current from the cathode to the plate if it is made negative enough before the plate voltage is applied to the tube. However, once the current begins to flow from the cathode to the plate of the tube, putting a negative voltage on the grid of the tube will not cut off the flow of plate current because the negative voltage attracts the positive gas ions in the tube and these ions draw electrons from the grid. If the grid voltage is high enough, this will cause such a high grid current that the tube may be destroyed.

The cathode ray tube is found in TV and in many pieces of test equipment. It contains an electron gun which is used to shape the electrons into a beam and to accelerate them down the gun towards the face of the tube. Electrons striking the face of the tube cause the tube to glow and give off light. Cathode ray tubes are made in two types, those using electrostatic deflection and those using electromagnetic deflection.

Other special tubes are the photo tubes and the voltage regulator tubes. You will see more of these tube types later.

SELF-TEST QUESTIONS

(au) What do we mean when we say a mercury-vapor fires?

(av) What is the advantage of a mercury-vapor diode over a vacuum-tube diode as a rectifier?

(aw) What is a thyratron?

(ax) What is the main difference between a thyratron and a conventional triode tube?

(ay) What is the purpose of the anodes in the electron gun of a cathode-ray tube?

(az) What two types of deflection may be used with a cathode-ray tube?

LOOKING AHEAD

Now that you have studied the various tube types and have learned how they operate, the next thing is to see them actually used in typical circuits. In your next lesson you will study the most common circuits found in electronic equipment. These circuits are the basic circuits from which more complex circuits have been developed.

ANSWERS TO SELF-TEST QUESTIONS

(a) A cathode and a plate.

(b) Tube cathodes can be divided into directly heated and indirectly heated types.

(c) A filament.

(d) By means of a heater which is a coil of wire placed inside the cathode. The cathode is usually made in the form of a hollow tube.

(e) To provide an abundant supply of electrons at low operating temperatures.

(f) None. Other than to heat the cathode the heater serves no useful purpose and therefore it is often left off the schematic diagram in order to simplify the diagram.

(g) Approximately 8 volts. The first number or numbers preceding the first letter in a tube type indicates the approximate heater voltage required by the tube.

(h) The plate or anode.

(i) The plate receives a certain amount of heating from the cathode of the tube and the remainder is produced by electrons striking it.

(j) The plate may begin to emit electrons and the excessive heat may force gases out of the plate material into the space surrounding the plate of the tube.

(k) The getter is used to eliminate gases that are released inside the tube the first time it is heated after it has been sealed.

(l) A tube from which all of the gases have been removed.

(m) A tube into which a certain amount of gas has been deliberately introduced. An example of the type of gas frequently introduced into diode tubes is mercury vapor.

(n) It simply indicates that a few electrons are missing the plate and striking the glass. This often happens and does not mean that there is anything wrong with the tube.

(o) When we say the plate current-plate voltage is linear we mean that a given change in plate voltage will produce a constant change in plate current. In other words, if we increase the plate voltage from 70 volts to 80 volts it will cause a certain increase in plate current. If we increase the plate voltage another 10 volts it will cause a similar increase in plate current.

(p) The grid is much closer to the cathode than the plate and therefore the voltage applied to the grid of the tube has a greater effect on plate current than the same voltage applied to the plate will have.

(q) The positive voltage applied to the grid of the tube will cause the number of electrons flowing from the cathode to increase. Most of these electrons will flow through the grid structure to the plate because the plate will normally have a much higher positive voltage than the grid. By the time the electrons have reached the grid they will be travelling at such a high speed that they will pass right through the grid and flow over to the plate. However, some of the electrons will be attracted by the grid and will cause some current to flow in the grid circuit.

(r) As the negative grid voltage is increased, the plate current will decrease until eventually the grid voltage will become negative enough to prevent any electrons from reaching the plate. When this happens we say that the plate current is cut off.

(s) The amplification factor of a tube is the ratio of the change in plate voltage to the change in grid voltage required to produce the same change in plate current.

(t) Between 5 and about 100.

(u) The amplified signal will normally be the same as the input signal except it will be 180° out of phase. In other words, when the input signal reaches its maximum positive value, the amplified signal will reach its maximum negative value and when the input signal reaches its maximum negative value, the amplified signal will reach its maximum positive value. We say that the output signal is inverted or 180° out of phase with the input signal.

(v) The ac plate current is the changing plate current produced by the input signal voltage. It acts like an ac current superimposed on the dc plate current that flows through the tube when the input signal is zero.

(w) A grounded-cathode amplifier is an amplifier using a tube in which the cathode is at signal ground potential.

(x) An E_g-I_p curve is a grid voltage-plate current curve. It shows how the plate current varies with different values of grid voltage.

(y) The linear portion of the E_g-I_p characteristic curve is the straight portion of the characteristic curve. In Fig. 15, the linear portion is between approximately -6 volts and 0 volts.

(z) A grid-bias voltage is a voltage applied between the grid and the cathode of the tube to fix the operating grid voltage so that the tube will operate over the linear portion of the E_g-I_p characteristic curve.

(aa) When a tube is operated with too low a grid bias, the signal may drive the grid in a positive direction. When this happens, the grid will draw current with the result that the increase in plate current will not be linear. This results in a flattening of one half of the amplified output signal.

(ab) When the operating grid bias on a tube is too high, the input signal may drive the grid so far in a negative direction that the flow of plate current may be completely cut off. This will result in a flattening of the negative half of the plate current cycle which will produce amplitude distortion.

(ac) An Ep-Ip curve is a characteristic curve which shows the plate current for different values of plate voltage. A series of these curves are usually given, one curve for each value of grid voltage.

(ad) The ac plate resistance of a tube is the ratio of a change in plate voltage to a change in plate current that it produces. It is represented by the formula:

$$r_p = \frac{e_p}{i_p}$$

(ae) The dc plate resistance of a tube is the dc plate voltage measured between the plate and cathode of the tube divided by the dc plate current flowing through the circuit.

(af) The mutual conductance of a tube is equal to a change in plate current divided by the change in grid voltage required to produce the change in plate current. Mutual conductance is usually represented by g_m and the formula for mutual conductance is

$$g_m = \frac{i_p}{e_g}$$

(ag) The mutual conductance is measured in mhos. However, the mho is a rather large unit and thus we usually convert this to micro-mhos by multiplying it by 1,000,000.

(ah) $\mu = r_p \times g_m$.

(ai) An equivalent circuit is a circuit used to analyze the performance of an amplifier stage.

(aj) The generator voltage is $-\mu e_g$. The voltage is negative to indicate the fact that it is inverted by the stage. In other words, the output voltage is 180° out of phase with the input voltage.

(ak) The generator internal resistance is the plate resistance of the tube.

(al) The stage gain will be 45. To find the gain of the stage we use the formula

$$\text{stage gain} = \mu \times \frac{R_L}{R_L + r_p}$$

and substituting 50 for the amplification factor, 90,000 for the load resistance and 10,000 for the plate resistance we get

$$\text{stage gain} = 50 \times \frac{90{,}000}{90{,}000 + 10{,}000}$$

$$= 50 \times \frac{90{,}000}{100{,}000}$$

$$= 50 \times \frac{9}{10}$$

$$= 45$$

(am) The screen grid reduces the plate-to-grid capacitance and prevents oscillation due to feedback from the plate to the grid of the tube.

(an) The screen of a tetrode tube is operated with a positive potential applied to it. Usually the positive potential is about half the plate potential.

(ao) The screen is operated at signal ground potential. We accomplish this by connecting a suitable capacitor between the screen of the tube and ground. The capacitor offers a low reactance to ac signals on the screen so, insofar as the signals are concerned, the screen is essentially at ground potential.

(ap) The five elements in the pentode tube are the cathode, the grid, the screen grid, the suppressor grid and the plate.

(aq) The grid and the screen grid. The voltage applied to the grid and the voltage applied to the screen grid will control the flow of plate current in a pentode tube. The plate voltage on a pentode tube has very little effect on the plate current flowing in the tube.

(ar) In a beam-power tube the electrons are focused in two beams. Electrons knocked off the plate are moving at a slow speed and they are repelled by the high-speed electrons in the beam back to the plate of the tube.

(as) A Compactron is simply a tube where several types have been combined in just one envelope. The base of the Compactron tube has twelve pins so that it is possible to combine a number of complete tubes in the same envelope.

(at) A Nuvistor is a miniature tube shaped something like a thimble with a flat top. The tube is extremely small and therefore the capacity between the plate and grid is quite low, making the tube suitable for use in rf amplifiers.

(au) When we say a mercury vapor tube fires we mean that the gas inside the tube ionizes.

(av) The mercury vapor tube has a constant voltage drop regardless of the current flowing through the tube. The vacuum type rectifier does not have this desirable characteristic; the voltage drop across the tube will depend upon the current flowing through the tube.

(aw) A thyratron is essentially a triode tube that has been filled with a gas such as mercury vapor.

(ax) In a thyratron, the grid can keep the plate current cut off if a high negative voltage is applied to the grid before voltage is applied to the plate of the tube. Once the plate current begins to flow, the grid loses all control of the flow of plate current and normally cannot be used to reduce or cut off the plate current. In a vacuum-type triode tube, however, the grid always maintains control over the flow of plate current.

(ay) The anodes are used to accelerate and focus the electron beam. They are not designed primarily to attract electrons as is the plate in the conventional tube, but rather they are used to accelerate electrons in the form of a beam down the electron gun towards the phosphor on the face of the cathode-ray tube.

(az) Electrostatic deflection and electro-magnetic deflection.

Lesson Questions

Be sure to number your answer sheet B110.

Place your Student Number on every Answer Sheet.

Most students want to know their grade as soon as possible so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of lessons before the new ones can reach you.

1. What type of emission is used in a vacuum tube with either a directly or an indirectly heated cathode?

2. Approximately what heater voltage would you expect a 12BE6 tube to require?

3. Why does secondary emission occur at the plates of most tubes?

4. If we find that in a certain triode tube a change in grid voltage of 2 volts produces the same change in plate current as a change in plate voltage of 100 volts, what is the amplification factor of the tube?

5. When the signal voltage swings the grid of the amplifier shown in Fig. 13 in a positive direction, in what direction does the plate voltage swing? Why?

6. Why do we apply grid bias to a tube?

7. Name the three important tube characteristics and give the formula for each.

8. Why can the stage gain of a triode amplifier never quite equal the amplification factor of the tube?

9. How does the suppressor in a pentode tube prevent the undesirable effects of secondary emission that occur in a tetrode?

10. How can you stop the flow of plate current in a thyratron once the tube has fired?

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ACHIEVEMENT THROUGH ELECTRONICS

HOW TUBES ARE USED

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HOW TUBES ARE USED

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STUDY SCHEDULE

By dividing your study into the steps given below, you can get the most out of this part of your NRI Course in the shortest possible time. Check off each step when you finish it.

☐ 1. Introduction . . . . Pages 1 - 2

☐ 2. Types of Amplifiers . . . . Pages 2 - 8

You learn that amplifiers can be divided into classes according to operation, and into voltage amplifiers and power amplifiers according to the applications for which they are used.

☐ 3. Typical Amplifiers . . . . Pages 9 - 18

In this section you study examples of both audio and rf amplifiers.

☐ 4. Detectors and Rectifiers . . . . Pages 19 - 23

We study detectors and rectifiers together in this section, because they both work on the principle of allowing current to flow in only one direction.

☐ 5. Oscillators . . . . Pages 24 - 28

You study the Hartley oscillator, the Colpitts oscillator, and the multivibrator.

☐ 6. A Complete Superheterodyne Receiver . . . . Pages 29 - 37

We take the various circuits you have studied and put them together to form a complete receiver.

☐ 7. Amplifier Variations . . . . Pages 38 - 43

We take up grounded-cathode, grounded-grid, and grounded-plate (cathode-follower) amplifiers.

☐ 8. Answers to Self-Test Questions . . . . Pages 44 - 48

☐ 9. Answer the Lesson Questions.

☐ 10. Start Studying the Next Lesson.

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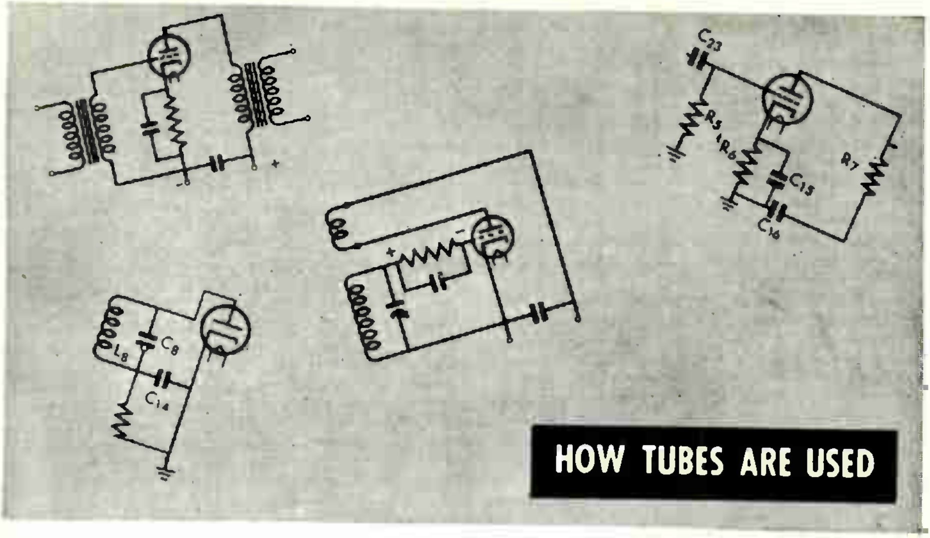

HOW TUBES ARE USED

In the preceding lesson you studied tube fundamentals and learned how a vacuum tube works. You learned that a tube is a unilateral device. By this we mean that it works in only one direction. Current will flow from the cathode to the plate of the tube, but it will not normally flow from the plate to the cathode.

You learned that in a three-element tube, a grid placed near the cathode can control the flow of electrons from the cathode to the plate. Because the grid is closer to the cathode than the plate is, it has a greater effect on the flow of plate current than the plate. Hence, a small signal voltage applied to the grid of a vacuum tube will cause the plate current to vary. This varying plate current can develop a voltage several times the original grid voltage across the plate load. This ability of the grid to control the flow of current from the cathode to the plate of the tube is what makes it possible for the tube to amplify a signal.

The purpose of this lesson is to increase your understanding of how tubes operate and to study a number of important basic tube circuits. You will study amplifiers similar to those used to amplify an audio or a video signal. You will study rf amplifiers, detectors and oscillators. All of these circuits will be found in modern electronic equipment. You will also study rectifiers. Although tube-type rectifiers are no longer used in new receiving-type equipment, they are still used in transmitters, in industrial applications and in many older radio and TV receivers.

These are the basic circuits that you are most likely to encounter. Later on, you will study many other circuits.

After we have looked at the basic circuits separately, we will see how these different circuits are used together to form a complete radio receiver. The basic principles used in radio receivers are similar to those used in both black and white and color television reception.

In the last section of the lesson we will take up some variations in amplifier circuits. In the simple amplifier you studied in the preceding lesson, the load was placed in the plate circuit of the tube and the cathode was operated at signal-ground potential. This type of amplifier is called a grounded-cathode amplifier. However, there are different circuits in which one of the other elements is operated at ground potential. In one type of amplifier the plate is grounded, and the load is placed in the cathode circuit. This type of amplifier is called a grounded-plate amplifier or more frequently a cathode-follower. In still another type of amplifier the grid is operated at ground potential, and the input signal is applied between the cathode and ground. The load is placed in the plate circuit. This type of amplifier is called a grounded-grid amplifier. In this lesson you will study all three types. While most of the amplifiers you will find are grounded-cathode amplifiers, grounded-grid amplifiers are used both in transmitting and receiving equipment. Also, cathode-followers are quite widely used in industrial applications, and they have been quite widely used in color TV receivers. The material you will study in this lesson is primarily an introduction to the different types of amplifiers. You will study them all in greater detail later.

Types of Amplifiers

Amplifiers can be divided into classes according to the amount of bias applied to the tube. You will remember that the bias is a negative voltage applied between the grid and cathode of a tube. If the bias applied to a tube is midway between zero bias and cut-off bias, the amplifier is called a Class A amplifier. A Class A amplifier operates on the linear or straight portion of the characteristic curve. Most of the amplifier stages found in radio and TV receivers are Class A amplifiers.

In some, the dc operating bias applied to a tube is equal to cut-off bias. This simply means that the negative voltage applied to the grid of the tube reduces the plate current to zero or almost to zero. This type of amplifier is called a Class B amplifier. It is found in medium and high power audio and video amplifiers and in radio and TV transmitters.

In still another type of amplifier the grid voltage applied to the tube is several times the negative voltage required to cut off the flow of plate current. This type of amplifier is called a Class C amplifier. Class C amplifiers are used as radio-frequency power amplifiers and as oscillators. You will see examples of all three classes of amplifiers in this lesson.

Amplifiers can also be divided into two general types, voltage amplifiers and power amplifiers. In a voltage amplifier we are interested in amplifying the signal voltage. A weak signal voltage is applied to the input circuit of the stage, and we are interested in getting as much amplification as possible. In other words we want as high an amplified voltage in the output as possible.

Usually, in order to get a high output voltage, the load used is a fairly high impedance or resistance.

In a power amplifier we are not particularly concerned about the amplitude of the voltage in the output. Instead, we are interested in getting as large a current variation from the tube as possible. Usually the load impedance is much lower in a power amplifier than it is in a voltage amplifier. However, in many cases it is difficult to tell a voltage amplifier from a power amplifier simply by looking at the circuit unless you know something about the value of the components used in the circuit and the conditions under which the tube is operated.

Voltage amplifiers are Class A amplifiers; power amplifiers may be Class A, B, or C.

VOLTAGE AMPLIFIERS

A simplified schematic of a typical voltage amplifier is shown in Fig. 1. Here the signal source is applied in the grid circuit between the grid and the cathode of the tube in series with the bias voltage. In the plate circuit of the tube we have the load connected in series with a B supply battery. The load and battery are connected between the plate and cathode of the tube. With a high-impedance load, small current variations flowing between the cathode and plate of the tube and through the load will result in comparatively large voltage variations across the load.

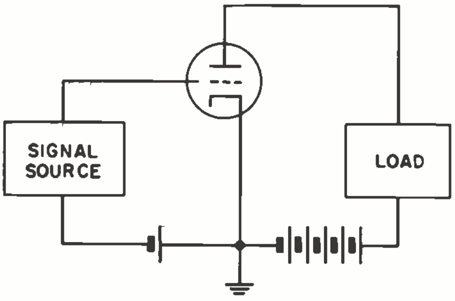

Fig. 1. A grounded-cathode amplifier.

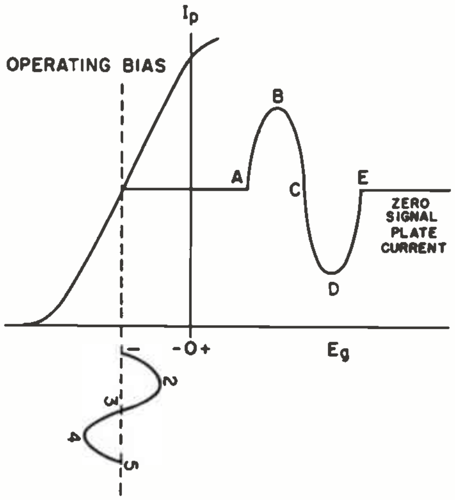

Fig. 2. Operating conditions of a typical voltage amplifier.

The graph in Fig. 2 shows how a voltage amplifier operates. Sufficient bias is applied to the tube to place the operating bias on the grid approximately midway between 0 and cut-off voltage. The idea is to bias the tube so that the tube will be operating on the linear portion of its characteristic curve. If we have too little bias on the tube, the grid may be driven positive, which will cause the grid to draw current; also the variations in plate current will not be linear. Similarly if too much bias is put on the tube, the grid will be driven beyond the cut-off point and there will be no plate current flow at all during part of the cycle of the input signal.

With the tube operated as shown in Fig. 2, the plate current variations follow the grid voltage. If the input signal swings in a positive direction it subtracts from the grid bias, making the bias less negative. This is what happens as the input moves from point 1 to point 2. As the input signal swings between these two points, the plate current moves from point A to point B.

During the next quarter of the input cycle, the grid voltage is swinging in a negative direction because the input signal is decreasing and dropping to zero as it moves from point 2 to point 3. At this point the signal has dropped to 0, and the voltage applied to the grid at this instant is the operating bias. During this quarter of the cycle the plate current moves from point B to point C.

During the next quarter cycle the input signal is swinging negative as it moves from point 3 to point 4. The signal now adds to the grid bias, making the voltage more negative. This results in the plate current dropping still further from point C to point D. When the input signal voltage reaches point 4 and starts to swing back to 0 again towards point 5, the grid becomes less negative, with the result that the plate current begins to increase and move from point D to point E.

There are several important things to be noted from the curve shown in Fig. 2. First, notice that the operating bias is approximately midway between 0 grid voltage and the grid voltage required for plate current cut-off. This places the operation of the tube on the linear or straight portion of the characteristic curve. As we have mentioned, an amplifier operated in this way, that is biased midway between zero voltage and cut-off voltage, is called a Class A amplifier.

Also notice that the input signal is small enough so that it neither drives the grid into the positive region nor does it drive it beyond cut-off. If the grid is driven positive or beyond cut-off, distortion will result, and the output signal will not be a faithful reproduction of the input signal.

Let us consider what happens to the plate current flowing in the tube. The line marked plate current represents the plate current that will flow when there is no input signal. Notice what happens when an input signal is applied. During one half cycle the plate current flow increases; during the other half cycle it decreases. The increase during one half cycle is equal and opposite to the decrease during the next half cycle. Therefore, if we consider the average plate current, it does not change. In other words, although the plate current does increase during one half cycle, it decreases by an equal amount during the next half cycle; the average plate current flowing remains the same as it was when no signal was applied to the input. Thus, if a dc milliammeter is placed in the plate circuit of a Class A amplifier, there will be no change in the reading when a signal is applied to the input because the meter will indicate the average dc flowing, and this does not change. If there is a change in the plate current, either the bias on the tube is incorrect or else the signal applied to the input is too strong and is driving the tube onto the non-linear portion of the characteristic curve.

The voltage amplifiers found in modern electronic equipment are Class A amplifiers. Thus, in a voltage amplifier you can expect to find that the output signal is a faithful reproduction of the input signal.

Furthermore you can expect to find the bias midway between zero bias and cut-off bias and also you can expect the average plate current flowing in the stage not to change when a signal voltage is applied to the input.

POWER AMPLIFIERS

Class A Amplifiers.

Class A amplifiers are used as power amplifiers but usually only when the amount of power required is comparatively low. The reason for this is that the Class A amplifier has relatively poor efficiency. The efficiency is the ratio of the power output to the power input.

It is easy to see why the efficiency of a Class A amplifier is poor. First, let's consider the operating curves shown in Fig. 3. Let's assume the tube is operating with a voltage of 200 volts applied to it and a plate current of 100 milliamperes. Thus the power input to the tube is 200 × .1 = 20 watts. This is the dc power input; it represents the power being taken from the power supply and fed to the tube.

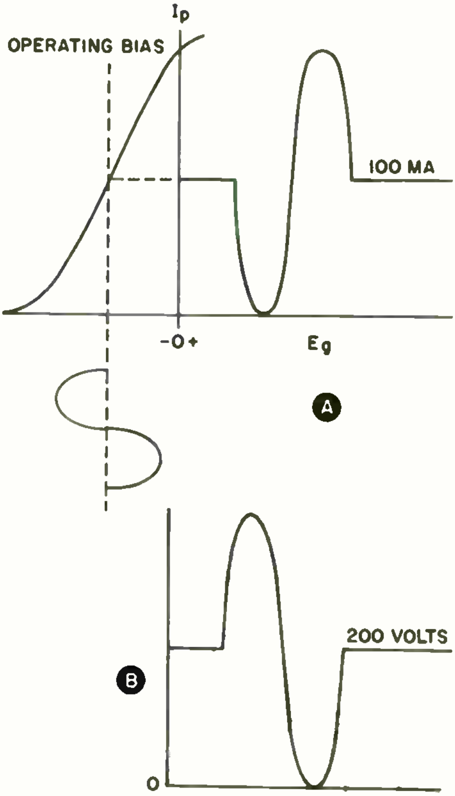

Fig. 3. Operating conditions for Class A operation.

Now let us consider how much signal power we can get out of this tube. If the current flowing in the tube is 100 milliamperes as shown in Fig. 3A, the maximum current change we can get in a half cycle is 100 milliamperes. In other words, if the grid voltage is swung all the way to the cut-off point by the input signal, then the plate current would drop to zero. This means that the peak current change is 100 mils, or .1 amp. The rms or effective current change, in amperes, will be only .707 of this value, or .1 × .707.

Similarly, the plate voltage applied to the tube is 200 volts as shown in Fig. 3B. The maximum change that could be made in plate voltage is 200 volts. To do this, the plate voltage would have to drop all the way to zero as the current through the load changed. Again this is the peak change, and the rms or effective change, in volts, is 200 × .707.

The maximum ac power output is equal to the effective ac voltage times the effective ac current. Therefore, the power output is equal to:

$$200 \times .707 \times .1 \times .707$$

If we multiply .707 × .707 we have .5, so we can express the formula as: 200 × .1 × .5. Now you will recognize the 200 × .1 as the input power, and we know that .5 is equal to 50%. Thus, the maximum power output that can be obtained from a Class A power amplifier is equal to 50% of the input power. Therefore, the best efficiency that can be obtained from a Class A amplifier is 50%. In fact, it is usually impossible to obtain this high an efficiency under actual operating conditions, because the grid would have to be driven all the way to cut-off on one half cycle, and all the way to zero on the other half cycle. Under these conditions, considerable distortion would result. Actually, the plate current would not be a sine wave as shown in Fig. 3, but would be flattened somewhat on both top and bottom. Efficiency of somewhere around 30% to 35% is usually about all that can be obtained from a Class A amplifier if reasonable linearity is to be maintained.

Class B Amplifiers.

Better efficiency can be obtained from a power amplifier if the bias on the tube is increased to approximately cut-off bias and a signal large enough to drive the grid positive is used. Under these conditions the operating curves for the tube will look like those shown in Fig. 4. When there is no signal applied to the input of the stage, the plate current flowing through the tube will be low. When the input signal swings in a positive direction, plate current flows in the form of a large pulse. When the signal swings in a negative direction, it soon drives the grid beyond the cut-off point and there will be no plate current flow in the tube. Thus you can see that the only time the tube is called on to furnish a large amount of power is when the grid is driven in a positive direction. For approximately half of each cycle there is no current flow through the tube at all.

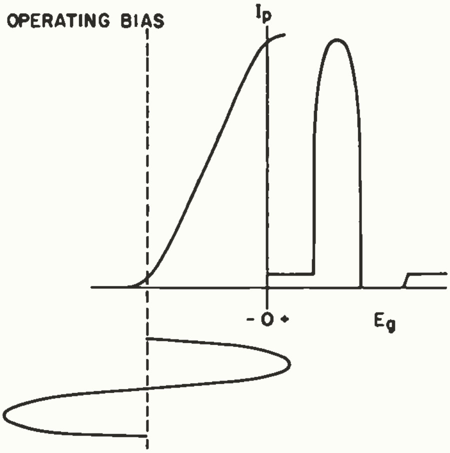

Fig. 4. Operating conditions for Class B operation.

It is immediately apparent that with this type of operation only one-half of the input signal is being reproduced. In an audio amplifier this would result in a great deal of distortion. However, this problem can be overcome by the use of two tubes, one to reproduce each half of the audio signal. By recombining the output from these two tubes, both halves of the audio signal can be reproduced. We will see examples of these circuits later in this lesson.

It is easy to see that this type of amplifier is more efficient than a Class A amplifier, because the current flowing through the tube when there is no signal present is comparatively small. Almost all of the current capabilities of the tube are reserved for the reproduction of the output signal. This type of operation, with the tube biased to cut-off, is called Class B operation. It is used quite extensively where large amounts of audio or video power must be developed, and it is also used to develop rf power in certain types of rf equipment.

Class C Amplifiers.

A still more efficient power amplifier than a Class B amplifier is the Class C amplifier. The curve shown in Fig. 5 shows how a tube is operated as a Class C amplifier. Notice that the operating bias is greater than the bias required to cut-off the flow of current through the tube. The Class C amplifier tube is generally operated with a bias somewhere between 2 and 4 times cut-off bias.

The input signal required for a Class C amplifier is considerably higher than that required for a Class A or Class B amplifier. The input signal drives the grid well into the positive region so that the grid draws substantial current. Plate current flows only in a series of pulses and these pulses actually flow for considerably less than half a cycle.

Class C amplifiers are not used for audio work, but they can be used as radio-frequency power amplifiers. They are used in conjunction with resonant circuits. If a parallel resonant circuit is placed in the output of a Class C amplifier, the pulse from the Class C amplifier will shock-excite the parallel resonant tank circuit into oscillation. If the tank circuit receives a pulse once each cycle, this pulse fed into the tank circuit is able to make up any losses in the tank circuit. Meanwhile, the current flows back and forth in the tank circuit so that the voltage appearing across it is actually a sine wave, even though it is being supplied energy only in the form of pulses. The tank circuit in a Class C amplifier has sort of a flywheel effect, and once oscillations are set up in it they can be maintained by pulsing it once each cycle.

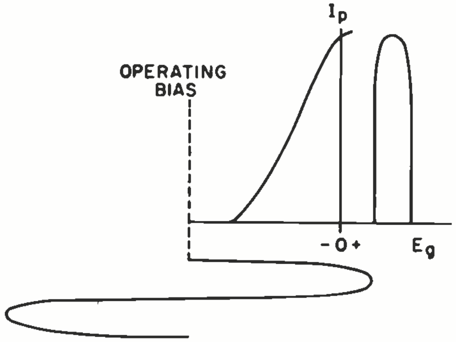

Fig. 5. Operating conditions for Class C operation.

As a matter of fact, the tank circuit can often be designed so that it does not need a pulse once each cycle but can maintain oscillations by receiving a pulse every other, or perhaps every third cycle. By designing the tank circuit in this way, it is possible to double or triple the frequency of the signal.

In addition to Class A, Class B, and Class C amplifiers there are also amplifiers known as Class AB amplifiers. As the name suggests, these are simply amplifiers operated midway between Class A conditions and Class B conditions. The operating bias applied to the tube is a little higher than that needed for Class A operation, but not as high as that needed for Class B operation. Beam power tubes are often operated under Class AB conditions.

SUMMARY

The important points to remember from this section are that there are three classes of operation for vacuum tubes. A tube that is operated with a bias midway between zero bias and cut-off bias is a Class

A amplifier. The output of this type of amplifier should be an exact duplicate of the input.

The Class B amplifier is operated at approximately cut-off bias. The zero-signal plate current flowing in this type of stage is low, and only the positive half of each cycle is reproduced. A Class C amplifier is an amplifier operated with bias several times cut-off bias. Plate current flows in this type of stage for less than half of each cycle.

Voltage amplifiers are Class A amplifiers. Power amplifiers may be Class A, Class B, or Class C. A Class A power amplifier has relatively poor efficiency. The efficiency of a Class B amplifier is better than that of a Class A amplifier, and the efficiency of a Class C amplifier is still better than the efficiency of a Class B amplifier. Class AB amplifiers are amplifiers operated under conditions between Class A and Class B.

SELF-TEST QUESTIONS

(a) What is a Class A amplifier?
(b) What is a Class B amplifier?
(c) What is a Class C amplifier?
(d) Into what two general types can amplifiers be divided?
(e) What is the purpose of a voltage amplifier?
(f) Into which class does the voltage amplifier fall?
(g) What is the disadvantage of a Class A power amplifier?
(h) What is the maximum possible efficiency that can be obtained from a Class A power amplifier? What is the practical efficiency of a Class A amplifier?
(i) Can a Class B power amplifier be used in audio power amplification?
(j) What type of signal is the Class C power amplifier used to amplify?
(k) What is a Class AB amplifier?

Typical Amplifiers

Look at Fig. 1 again, where we have shown a simplified diagram of an amplifier. As you can see from this diagram, the basic parts of an amplifier are the tube, the load, and batteries or some other power source to supply the power needed to operate the tube. Now, let us study some practical amplifiers to see how the various electronic components you have already studied are used in conjunction with tubes in order to amplify signals.

AUDIO AMPLIFIERS

An audio amplifier is an amplifier designed to amplify signal frequencies within the range normally heard by our ears. Some amplifiers are capable of doing this job better than others. The audio amplifier found in the average radio or TV receiver is not capable of reproducing all of the frequencies that our ears can hear. However, an amplifier designed for use in a piece of high-fidelity equipment has a much better frequency response and can amplify a wider range of frequencies. Amplifiers found in most radio and TV receivers can amplify frequencies from about 50 or 60 cycles per second up to 8000 or 9000 cycles per second. Amplifiers designed for use in high-fidelity equipment can amplify frequencies from about 10 cycles per second up to at least 15,000 cycles per second and sometimes as high as 100,000 cycles per second.

Audio amplifiers may be either voltage amplifiers or power amplifiers. Voltage amplifiers are used to build up the strength of the weak audio signal until it is strong enough to drive a power amplifier. A power amplifier is then used to supply the power to drive the speaker.

Voltage Amplifiers.

A typical voltage amplifier is shown in Fig. 6. This amplifier is called a resistance-capacitance coupled amplifier because resistors and capacitors are used to couple the signal to the amplifier and to the output or to the following stage.

In the circuit shown in Fig. 6, capacitor C1 is used to couple the signal source to the grid of the tube. C1 will block any dc in the input circuit and keep it away from the grid of the tube. At the same time, if C1 is large enough, it will offer a low reactance to the flow of an ac signal through it and act, as far as the ac signal is concerned, as though it were not there at all. The input signal is therefore applied between the grid of the tube and ground.

Resistor R1 is called a grid leak. Some of the electrons travelling from the cathode to the plate of the

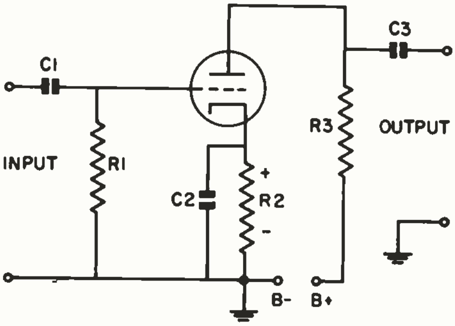

Fig.6. A typical resistance-capacitance coupled amplifier.

tube will accidentally strike the grid. If there is no way for these electrons to get off the grid of the tube, they will be trapped on the grid and eventually build up a high negative charge on the grid. This negative charge will reduce the flow of current from the cathode to the plate of the tube. As a matter of fact, in some tubes this charge may become so high it can actually cut off the flow of electrons from the cathode to the plate of the tube.

As long as R1 is in the circuit, electrons striking the grid can flow through R1 back to ground and then through R2 back to the cathode of the tube. Of course, when electrons flow through a resistor they build up a voltage across the resistor. Electrons flowing from the grid of the tube back to ground will develop a dc voltage across R1 having a polarity such that the grid end of the resistor is negative. Normally in an amplifier of this type, however, the number of electrons flowing through the grid resistor is not large enough to develop any appreciable voltage across the grid resistor, R1, even though the value of the resistor may be quite large. Resistors of 100,000 ohms to 500,000 ohms are frequently used as grid resistors. Usually it will be impossible to detect any voltage across these resistors, even with quite sensitive measuring equipment.

Capacitor C1 and resistor R1 actually form a voltage-divider network that divides the ac signal voltage. If R1 is made large in comparison to the reactance of C1, most of the signal voltage will appear across R1. This means that most of the signal voltage will be applied between the grid of the tube and ground, which is essentially where we want it. On the other hand, if R1 is small compared to the reactance of C1, then C1 and R1 will divide the signal voltage so that only a small part of it will appear across R1; the remainder will be lost across C1. This situation is to be avoided if maximum output is to be obtained from the amplifier. For this reason, designers make R1 as large as practical.

While we are discussing the combination of C1 and R1, remember that the reactance of a capacitor depends upon the frequency of the signal voltage. As the frequency decreases, the reactance increases. Therefore, at low frequencies the reactance of C1 may become large enough to appreciably reduce the voltage across R1. When this happens, the signal amplification will fall off; the amplifier will not amplify low-frequency signals as well as it does higher-frequency signals. Making R1 large tends to extend the low-frequency gain of an amplifier.

On the other hand if R1 is made too large, then the electrons accidentally striking the grid of the tube will develop an appreciable dc voltage across R1 when they flow through it. In an amplifier like the one shown in Fig. 6, this voltage is undesirable. Therefore the value of R1 must be a compromise. It is made as high as possible, so that the signal voltage will be high, without making it so high that a troublesome dc voltage will be developed across it.

The dc voltage supply used to supply the plate voltage to the tube is represented by the terminals B- and B+. This could be a B battery or it could be the terminals of a power supply. A power supply is a unit that converts ac from the power line to dc for use in applications such as this. You will study power supplies shortly.

Resistor R2 is put in the cathode circuit of the tube to eliminate the need for a C battery to supply a grid bias voltage. Let's consider what happens with this resistor in the circuit. Electrons flowing through the tube are emitted by the cathode, attracted by the plate, then flow through R3, then through the B supply to ground, and finally through R2 back to the cathode. The minute power is applied, this action is instantaneous, and electrons start flowing in all parts of the circuit. The electrons flowing through R2 will develop a voltage across this resistor with the polarity indicated on the diagram. This makes the cathode slightly positive with respect to ground. If the tube is designed to operate with a grid voltage of -3 volts, R2 is selected so that the electrons flowing through it will develop a voltage of 3 volts across the resistor. This will make the cathode 3 volts positive with respect to ground.

To see how this voltage biases the tube and eliminates the need for a C battery, let us consider the potential of the grid with respect to ground. The number of electrons flowing through R1 is so small that little or no voltage is developed across it. Therefore, the grid is normally at ground potential. This means that the cathode is positive with respect to the grid. If the cathode is positive with respect to the grid, then the grid is negative with respect to the cathode.

R2 is often called a cathode bias resistor. By using this resistor in the cathode circuit, we can eliminate the need for a C battery. Batteries deteriorate and have to be replaced periodically, whereas the resistor will last almost indefinitely providing it is not overloaded.

Capacitor C2 is connected across R2 in order to stabilize the voltage across R2. Without C2, as the input signal caused the tube current to vary, the current through R2 would vary. This would result in varying voltage or varying bias across the resistor. To eliminate this effect, we connect capacitor C2 across the resistor. C2 must be large enough to maintain the voltage across R2 constant. It does this by charging when the current through R2 increases and the voltage tends to rise, and discharging through R2 when the voltage tends to fall. The capacitor actually acts as a low reactance path for the ac signal through it. The grid of the tube, in causing the plate current to vary, is actually producing an ac signal superimposed on the dc in the plate-cathode circuit. This ac signal component flows through C2; the dc component flows through R2.

Resistor R3 is the plate load resistor. The value of this resistor is usually quite large. The larger the resistor, the closer the gain of the stage will approach the amplification factor of the tube. You will remember that the tube acts like a generator, and this generator has an internal resistance, the ac plate resistance of the tube. Resistance R3 is, in effect, connected in series with the plate resistance of the tube, and the voltage developed by the tube is divided between the plate resistance and the plate load. By making the plate load resistor as large as possible, we will get as much of the amplified signal voltage across this resistor as possible.

However, there is a limit to how large we can make this resistor.

Since the plate current flows through the resistor, there will be a voltage drop across the resistor. This voltage drop subtracts from the supply voltage so that the net voltage available to operate the tube is equal to the supply voltage minus the voltage drop across the plate load resistor. If we make the plate load resistor too large, there will be a very high voltage drop across it with the result that there is very little voltage left to operate the tube. Again, the selection of the size of resistor to be used is a compromise. A value is chosen that will give a reasonably high gain without an excessive voltage drop. If the voltage drop across R3 is excessive, then the power supply voltage must be very high in order to get the voltage we need on the plate of the tube. This could require a costly power supply, so it is often more economical to use two stages to get the gain we need than to try to get it from one stage by using an excessively large plate-load resistor.

A schematic diagram of another voltage amplifier is shown in Fig. 7. This amplifier is called a transformer-coupled amplifier. Notice that in some respects the circuit is similar to the circuit shown in Fig. 6. In the transformer-coupled amplifier, transformer T1 is taking the place of C1 and R1 in the resistance-coupled stage. Similarly, transformer T2 is taking the place of load resistor R3 and blocking capacitor C3 in the output. Both transformers can be step-up transformers, so that there will be voltage amplification in the transformers themselves as well as in the tube. Bias for the stage is still obtained by placing a resistor in the cathode circuit of the tube. R1 in Fig. 7 is the cathode-bias resistor, and it is bypassed by the capacitor C1.

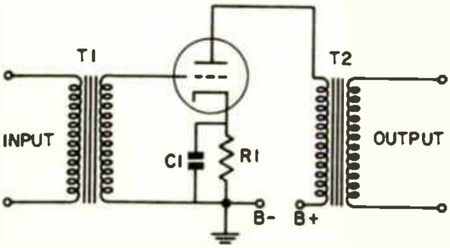

Fig. 7. A transformer-coupled amplifier.

Transformer-coupled amplifiers of this type are not used in modern electronic equipment. The transformers are more expensive than the resistor-capacitor combination, and modern tubes have such high gain that it is not necessary to rely on the step-up transformer to get a reasonable gain in the stage. However, you may be called on to service an older piece of equipment that might employ a transformer-coupled stage, so you should be aware that this type of coupling exists.

Power Amplifiers.

Fig. 8A shows a power amplifier using resistance-capacitance coupling in the input circuit. The input circuit is essentially the same as the circuit used in Fig. 6.

The output transformer is a step-down transformer. This transformer is primarily an impedance-matching device. It is used to match the low-impedance speaker, which would be connected across the output terminals, to the plate circuit of the tube. Remember that the tube works like a generator, and maximum power transfer will be obtained when the load matches the generator. The transformer matches the load impedance to the generator or tube impedance.

Fig. 8B shows a transformer-

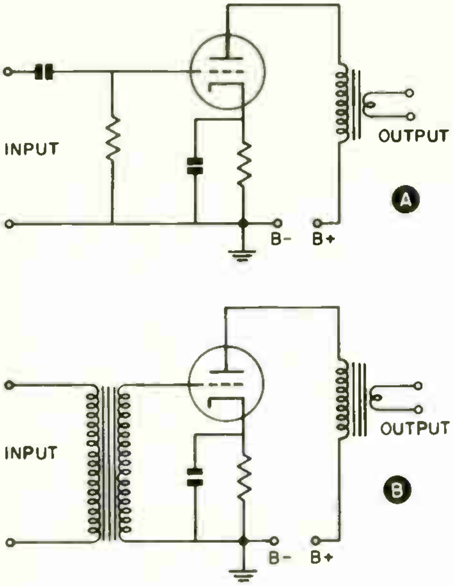

Fig. 8. Two single-ended power amplifier stages.

coupled power amplifier. The input transformer is a step-up transformer, and the output transformer will be a step-down transformer to serve as an impedance-matching device. The circuit shown in Fig. 8B is obsolete; you will not run into a circuit of this type except in old equipment.

Both of the amplifiers shown in Fig. 8 are Class A power amplifiers. They are also called single-ended stages because each circuit uses a single tube. In some audio amplifiers, in large radio receivers, and in some TV sets you will run into a double-ended power output stage such as the one shown in Fig. 9. This circuit is called a push-pull amplifier. It can be operated as either a Class A, Class AB, or a Class B power amplifier. If the stage is operated as a Class A power amplifier, the stage preceding it can be a voltage amplifier and T1 may be a step-up transformer. On the other hand, if the stage is operated as a Class B amplifier the stage preceding it must be a power amplifier because power must be supplied to the grid circuit, and T1 must be a step-down transformer.

If the stage is a Class AB$_1$ power amplifier, the preceding stage can be a voltage amplifier since the grid does not draw current and no power is consumed in the grid circuit. On the other hand, if the stage is a Class AB$_2$ power amplifier, the grid does draw grid current and power must be supplied to the grid circuit. The preceding stage, therefore, must be a power amplifier.

This stage is called a push-pull amplifier because it acts as though one tube is pushing electrons through the primary of T2 while the other is pulling electrons in the opposite direction. Briefly, the operation of

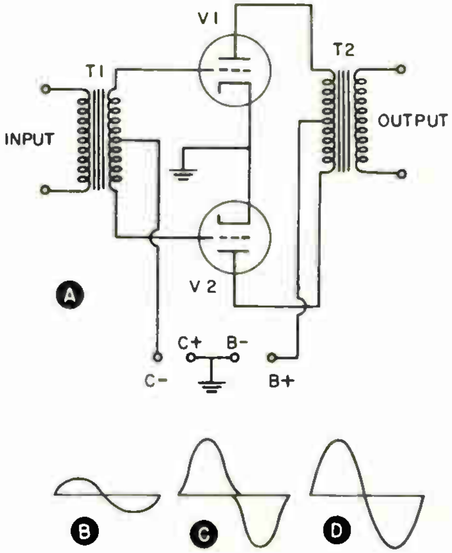

Fig. 9. A push-pull amplifier stage is shown at A, the input signal is shown at B, the output pulses from the two tubes at C, and the combined output at D.

the stage is as follows: the secondary of transformer T1 is tapped, and the center tap is at signal ground potential. When the end of the secondary of T1 that is connected to V1 is swinging positive with respect to ground, the other end will be swinging negative with respect to ground. The positive voltage applied to tube V1 will cause its plate current to increase, while the negative voltage applied to the grid of V2 will cause its plate current to decrease. Thus the current in one half of T2 increases while the current in the other half of T2 decreases. During the next half cycle, when the end of the secondary of T1 that is connected to V2 is positive with respect to ground, the other end will be negative. At this time the plate current of V2 will increase while the plate current of V1 decreases.

When this type of stage is used as a Class B amplifier, the tube that is driven positive conducts current heavily while the other tube does not conduct current at all. During the next half cycle the second tube carries the whole load while the other tube rests. If the input signal is a sine wave like that shown in Fig. 9B, the plate currents for the two tubes look like Fig. 9C and combine to produce a signal like Fig. 9D in the secondary of transformer T2. This explains how two tubes can be used in a Class B amplifier to amplify an audio signal when each tube conducts during only half of each cycle. One tube reproduces one half of the cycle; the other tube reproduces the other half of the cycle. The two signals are combined in transformer T2 to give an output signal that is an amplified reproduction of the input signal.

Push-pull amplifiers are used in some radio and TV receivers. They are found in high-fidelity equipment and in many radio and television transmitters. Push-pull amplifiers are used wherever it is necessary to develop a large amount of audio or video power. Operating these tubes as Class B amplifiers gives much better efficiency than operating them as Class A amplifiers. As a matter of fact, the same amount of audio power can usually be developed more economically by using two small tubes operated as Class B amplifiers than by using one large tube operated as a Class A amplifier.

RADIO-FREQUENCY AMPLIFIERS

Radio-frequency amplifiers like audio amplifiers can be divided into two types, voltage amplifiers and power amplifiers. The radio-frequency amplifiers found in receiving equipment are voltage amplifiers, whereas those found in transmitting equipment are power amplifiers. In receiving equipment, we are interested in taking the weak radio-frequency signal picked up by the antenna and amplifying it in order to extract whatever intelligence it may carry. In transmitting equipment, we are interested in developing power to feed to the antenna in order to radiate a strong signal.

Voltage Amplifiers.

A radio-frequency voltage amplifier is shown in Fig. 10. Notice that in many respects it is similar to the single-ended transformer-coupled audio amplifier. In the rf amplifier, we have used a pentode. Triodes are not as suitable as pentodes in rf amplifiers in most cases. Notice that both the input and output circuits are tuned. These circuits are

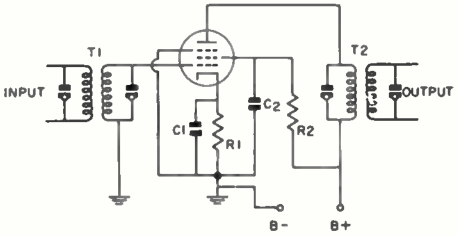

Fig. 10. A radio-frequency voltage amplifier.

adjusted to resonance at the frequency of the rf signal.

As in the audio amplifiers we studied, operating bias for the stage is obtained by inserting a resistor in the cathode circuit. This is the resistor marked R1 on the diagram; it is bypassed by capacitor C1. The purpose of capacitor C2 is to ground the screen of the tube insofar as signal voltages are concerned. Capacitor C2 is selected so that its reactance is low at the operating frequency. Thus, insofar as the signal is concerned, the screen is in effect operating at ground potential. This isolates the plate from the grid of the tube so that there is not enough energy fed from the plate of the tube back to the grid to cause the tube to go into oscillation. Resistor R2 is called the screen dropping resistor. Its purpose is to drop the B supply voltage to a suitable value for the screen. In many voltage amplifiers of this type, the screen voltage is somewhat less than the plate voltage. Plate voltage is applied to the tube through the parallel resonant circuit installed in the plate circuit.

With modern pentode tubes, a comparatively high voltage gain can be obtained in a stage of this type. It is easy to get a gain on the order of 100.

Power Amplifiers.

Radio-frequency voltage amplifiers are biased to operate at the mid-point of the characteristic curve. In other words, they are Class A amplifiers. However, rf power amplifiers are usually operated either in Class B or in Class C, although some rf power amplifiers operate in Class AB. A schematic diagram of a Class C rf power amplifier is shown in Fig. 11. Notice that this circuit differs somewhat from the voltage amplifier.

In this circuit, bias is obtained by means of a resistor in the grid instead of the cathode circuit. In a Class C amplifier a high value of bias is used. The signal applied to a Class C stage must be sufficient to drive the grid positive. When the grid is driven positive, electrons will leave the cathode and strike the grid to charge C2 with the polarity shown. During the time when the input signal is not positive, C2 will discharge through RFC and R1, making the grid negative with respect to ground. By selecting the proper value of R1, the correct bias can be developed across this resistor.

Since the tube in a Class C amplifier is normally operated at bias voltages several times cut-off, plate current does not flow through the tube except when the input signal

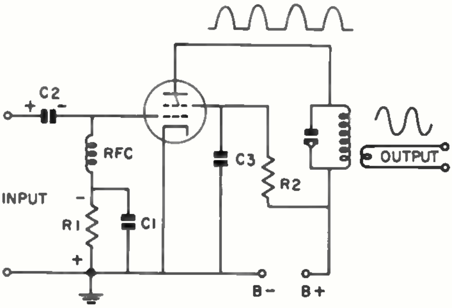

Fig. 11. Schematic of a Class C rf power amplifier.

swings positive and drives the grid into the region where plate current can flow. Current then flows from the cathode to the plate of the tube in the form of a series of pulses as indicated. These pulses shock-excite the parallel resonant tank circuit, consisting of the primary of the output transformer and the capacitor across it, so that current flows back and forth between the coil and capacitor, producing the sine wave output shown.

Class C rf power amplifiers have very high efficiency--in the range of 75%. This means that for each watt that is fed into the amplifier plate circuit, about 3/4-watt of rf power can be developed. The efficiency of this type of amplifier is somewhat better than that of a Class B amplifier and is much better than that of a Class A amplifier.

The stage shown in Fig. 11 is a single-ended stage. Push-pull Class C rf amplifiers can also be used. The power output of this type of stage is approximately double what could be obtained from a single-ended stage using the same tube type.

EFFICIENCY OF AMPLIFIERS

The amount of power you can get from a tube depends on which class of amplifier stage it is used in. As you have learned, a Class A stage has a practical efficiency of about 30 per cent. This means that 70 per cent of the power fed to the stage is lost. Most of this power is wasted at the plate of the tube. We say it is "dissipated" by the tube.

All power tubes have a rating known as the plate dissipation. This rating tells how much power can be dissipated at the plate of the tube without overheating the tube. Consider a power tube with a plate dissipation rating of 10 watts. If we use this tube in a power amplifier, we cannot let the plate dissipate more than 10 watts. This means that if the amplifier is a Class A amplifier with an efficiency of 30 per cent, 70 per cent of the input must not exceed 10 watts. The total power input to the stage must not exceed:

$$10 \times \frac{100}{70} = 14.28 \text{ watts}$$

This means the total power input to the stage should be about 14 watts, and the power output will be about 4 watts. The remaining 10 watts will be dissipated by the tube.

In a Class B amplifier we will get much better efficiency than in a Class A amplifier. The efficiency will be between 50 and 60 per cent. Let's see what power we can get out of the same tube as in the preceding example in a Class B stage with 50 per cent efficiency.

In the Class B stage, the total power input to the stage must not exceed:

$$10 \times \frac{100}{50} = 20 \text{ watts}$$

This means that with an efficiency of 50 per cent, the power input will be 20 watts and the useful power output 10 watts. The remaining 10 watts will be dissipated by the tube. Notice that we have over twice the power output that we got from a Class A amplifier, and that the plate dissipation rating of 10 watts has not been exceeded.

Let's go one step farther and see what would happen if we used the same tube in a Class C amplifier with an efficiency of 75 per cent. Here the maximum power input to the stage can be:

$$10 \times \frac{100}{25} = 40 \text{ watts}$$

This means that with an efficiency of 75 percent, the power input to the stage can be 40 watts and the useful power output 30 watts. The remaining 10 watts will be dissipated by the tube.

Notice how the efficiency of the amplifier improved as we went from a Class A amplifier to a Class B amplifier. We got a higher per cent of the input power out as useful output power. You can see a still further improvement in going to a Class C stage. Another point that you should notice is the increase in total power that can be handled by a tube in going from a Class A stage to a Class C stage. In a Class A stage, the power input could be a maximum of about 14 watts, but in a Class C stage we can feed 40 watts to the stage. Thus, the efficiency of the stage and the plate dissipation rating of the tube determine the permissible power input to the stage. The input must be limited so that the power wasted in the stage does not exceed the plate dissipation rating of the tube. The power wasted will be determined by the input power and the efficiency of the stage.

SUMMARY

In this section of this lesson we have covered a number of different types of circuits. We do not expect you to remember all the details of each type of circuit at this time. The important thing for you to remember is that there are two types of amplifiers, voltage amplifiers and power amplifiers. Remember also the general appearance of the different circuits. The best way to remember these circuits is by actually drawing them. Notice the similarity between the different types of circuits. In the input of each stage, there is a means of applying the signal between the control grid and cathode of the tube. In each stage, there is some method of developing the required bias. In addition, in each stage you will find some type of load in the plate circuit. By carefully studying these different circuits you will see that there is a great deal of similarity between them and that each circuit is in fact like the basic circuit shown in Fig. 1, but modified for the particular application for which it is designed.

You will study all these circuits in more detail later on, but if you can learn what the circuit looks like now and in general how the amplifier works, you will find it much easier to pick up the various circuit details later.

SELF-TEST QUESTIONS

(l) Into what two types of amplifiers can we divide audio amplifiers?

(m) Try to draw from memory a schematic diagram of a resistance-coupled voltage amplifier.

(n) How is the grid-bias battery eliminated in a typical voltage amplifier?

(o) What limits the size of the resistor that can be used as the grid leak in a voltage-coupled amplifier?

(p) What is the purpose of the bypass capacitor connected across the cathode-bias resistor?

(q) In the power amplifier circuit shown in Fig. 8A, is the output transformer a step-up transformer or a step-down transformer?

(r) Fill in the missing words: a power amplifier using one tube such as shown in Fig. 8 is called a ____________ ended stage whereas one using two tubes such as shown in Fig. 9 is called a __________ ended stage.

(s) What type of amplifier, a voltage amplifier or a power amplifier, is used as the rf amplifier in a radio or TV receiver?

(t) What is the purpose of the capacitor C3 in the rf power amplifier shown in Fig. 11?

(u) Which class of power amplifier has the best efficiency? Which class has the poorest efficiency?

Detectors and Rectifiers

Tubes were used for many years as detectors and rectifiers. However, they are not used for this purpose in modern equipment nearly as often as solid-state devices are. You will study solid-state detectors and rectifiers shortly, but now you will study tube detectors and rectifiers. You will find some tubes used as rectifiers even in modern equipment and, of course, you will probably service many pieces of equipment where tubes have been used as both detectors and rectifiers.

We will study detectors and rectifiers together, because the detector is basically a rectifier. They both work on the principle of allowing current to flow in only one direction. There are, however, some differences in their application. A rectifier is used to change alternating current to direct current. A detector is used to extract information from a radio-frequency carrier.

RECTIFIERS

There are a number of different types of rectifier circuits found in electronic equipment. We will look into two of these circuits in some detail and see in general how these circuits work. There are many details that you will study later.

Half-Wave Rectifiers.

A half-wave rectifier is one that rectifies only half of the ac power-line cycle. During one half cycle, one terminal of a generator is positive and the other terminal is negative. During the next half cycle the terminal that was originally positive becomes negative, and the terminal that was originally negative becomes positive. In a half-wave rectifier circuit the rectifier is arranged so that it conducts when one of these generator terminals is positive but does not conduct when this terminal becomes negative.

A schematic diagram of a half-wave rectifier along with a filter network is shown in Fig. 12. This type of rectifier and power supply is called a universal ac-dc power supply. It is the type of power supply that was used for many years in almost all of the table-model radio receivers manufactured. Even though it is seldom used in modern receivers, the chances are that receivers using this type of supply will be around for many years, and you'll be called on to service a set using this type of power supply. It's called an ac-dc power supply because when it is used in a receiver the receiver can be used on either ac or dc power.

During ac operation, when terminal 1 is positive with respect to terminal 2, the plate of the tube is positive. Thus electrons will be at-

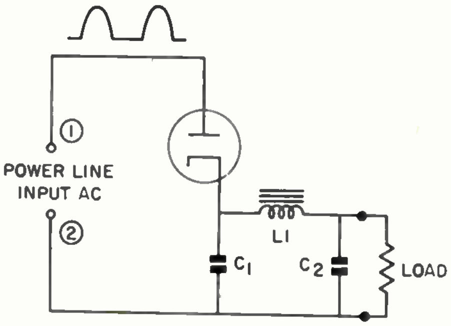

Fig. 12. A half-wave rectifier circuit and a filter network.

tracted from the cathode of the tube to the plate. The complete path for electrons is from terminal 2 through the load, through the filter choke L1, to the cathode of the tube and then through the tube to the plate and back to the other side of the power line. When the polarity of the power line reverses, the plate of the tube becomes negative, and there will be no current flow through the tube and hence no current drawn from the power line.

In a half-wave rectifier, current flows from the power line in a series of pulses as shown in the figure. When the power-line voltage becomes greater than the voltage stored in capacitor C1, there is a large pulse of current that flows through the rectifier tube. This charges capacitor C1. During the remainder of the cycle no current flows through the rectifier tube, and capacitor C1 can be considered as supplying power to the circuit during this part of the cycle. The action of filter choke L1 and filter capacitor C2 is to help smooth the pulsating current to pure dc. The action of these components will be treated in a later text.

Although tube type half-wave rectifiers of the tube just studied are not used in modern receivers, very similar types of rectifier circuits using tubes are still widely used as high-voltage rectifiers in both black and white and color TV receivers and in a circuit called the damper stage in TV. When you study these circuits later in your course, you will see that they are both forms of the half-wave rectifier circuit.

Full-Wave Rectifiers.

The schematic diagram of a full-wave rectifier is shown in Fig. 13. This type of circuit was widely used in both radio and television receivers for many years. Therefore, even though it has been replaced by power supplies using solid-state rectifiers, you should know how it works because you can be sure you will run into power supplies of this type.

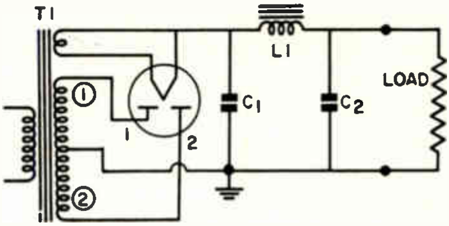

Fig. 13. A full-wave rectifier circuit and a filter network.

In this type of circuit, the high-voltage winding on the power transformer is center tapped, and the center tap is connected to ground. One end of the high-voltage winding is connected to one plate of the rectifier tube, and the other end is connected to the other plate of the rectifier tube. Insofar as the tube operation is concerned, it acts like two separate diodes. When the terminal marked 1 on the high-voltage secondary is positive with respect to the center tap, terminal 2 will be negative with respect to the center tap. Thus the rectifier plate that is connected to terminal 1 will be positive and the rectifier plate connected to terminal 2 will be negative. During this half cycle, current flows from the center tap of the high-voltage winding on the transformer, through the load, through the filter choke to the filament of the rectifier tube. Current then flows from the filament to plate 1 to terminal 1 of the power transformer.

During the next half cycle, terminal 1 of the transformer will be negative with respect to the center tap, and terminal 2 will be positive. During this half cycle, current flows from the center tap through the load, through the filter choke, to the filament of the rectifier tube, to plate 2 of the rectifier tube and then to terminal 2 of the transformer.

As you can see, in the full-wave rectifier circuit of this type current flows first through one half of the high-voltage secondary winding and one half of the tube and then through the other half of the high-voltage secondary winding and the other half of the tube. Thus, if the power supply is operated from a 60-cycle power line there will be two current pulses each cycle. This means that there will be 120 pulses available to charge the filter capacitor marked C1. This is twice as many pulses as can be obtained from the half-wave rectifier. The greater the number of pulses, the easier it is to obtain pure dc. Therefore, it is much easier to filter the pulsating dc at the output of a full-wave rectifier than at the output of a half-wave rectifier.

Pulsating dc at the output of the rectifier is often referred to as dc with a ripple voltage or hum voltage superimposed on it. You will see later that there will always be some ripple present at the output of the power supply regardless of how effective a filter network is. The filter network is designed to cut the ripple to such a low value that it does not appreciably affect the performance of the equipment. The filter systems in most power supplies reduce the ripple voltage so that it is 1% or less of the dc output voltage.

DETECTORS

There have been a number of different kinds of detectors used in electronic equipment, but most pieces of modern electronic equipment use a diode detector. A schematic diagram of a diode detector using a vacuum tube is shown in Fig. 14.

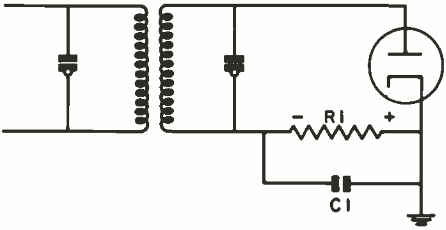

Fig. 14. A diode detector circuit.

The diode detector shown in Fig. 14 works in much the same way as the half-wave rectifier. When the plate of the tube is positive, current flows through the tube; when it is negative, current cannot flow.

To see how the diode detector can extract intelligence from a radio-frequency signal, let's look at the modulated rf carrier shown in Fig. 15A. We see here an example of amplitude-modulated radio frequency signals. The amplitude or strength of the radio-frequency signal is varying at an audio rate. The audio signal is the intelligence being transmitted.

In the diode detector circuit the current that flows will depend upon the strength of the rf signal applied to it. Thus, as the strength of the rf signal varies, the strength of the pulses of current flowing through the tube will vary. The current flowing through the tube will flow from the cathode to the plate of the tube, through the secondary of the i-f transformer and then through the load resistor R1, setting up a voltage drop across this resistor having the polarity shown on the diagram. The voltage across this resistor will charge capacitor C1. As the strength of the signal varies, causing the current to vary, the voltage across R1 and hence the charge across C1 will vary. Since the strength of the rf signal is varying at an audio rate, the voltage across R1 will vary at an audio rate. This will cause a voltage to appear across R1 and C1 like the voltage shown in Fig. 15B. Notice that this is the audio signal that was actually being carried by the rf signal.

It might be well to point out at this time that the current flows through the diode in a series of pulses like those shown in Fig. 15C. Notice that these pulses are somewhat similar to the pulses obtained from a half-wave rectifier with the exception that the amplitude of these pulses is varying. These pulses tend to charge capacitor C1. The charge across the capacitor will be determined by the amplitude of the pulses, which in turn is determined by the strength of the signal being received and the amplitude modulation on the signal.

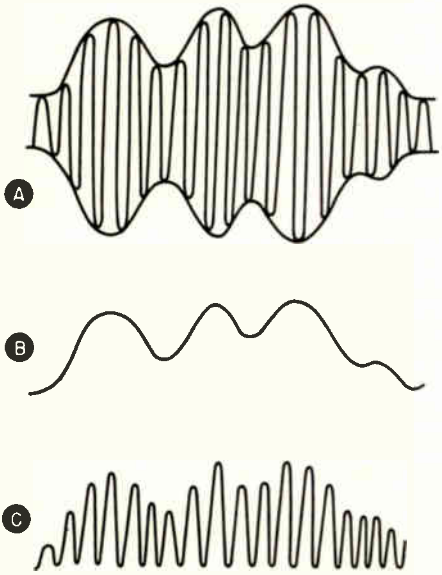

Fig. 15. A modulated rf carrier is shown at A, the extracted audio signal is shown at B, and the series of current pulses flowing through the diode are shown at C.

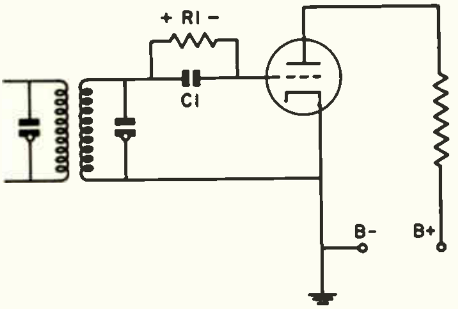

Fig. 16. A grid-leak detector.

In the interval between each cycle there is some tendency for the capacitor to discharge through the resistor, but if the values of the capacitor and the resistor are selected correctly, the discharging is so small that it does not cause any appreciable difficulty. On the other hand, C1 and R1 must be selected so that they are not too large, because C1 must be able to discharge rapidly enough to follow the audio signal variations.

Triode Detectors.

A diode is not the only tube that can be used as a detector. One of the earliest forms of detector was the triode grid-leak detector. The schematic of a grid-leak detector is shown in Fig. 16. The operation of this type of detector is not a great deal different from the operation of a diode detector followed by a triode audio amplifier. If for the present we ignore the plate of the tube and consider only the grid and the cathode, you will see that the circuit is very similar to that of a diode detector. All we would need to do is move the resistor and capacitor to the other side of the transformer to give us the identical circuit.

In a grid-leak detector the rectification actually occurs in the grid circuit with the grid acting like a diode plate. When the rf signal drives the grid positive, electrons are attracted to the grid and current flows to charge the grid capacitor C1. When the rf signal swings negative and there is no grid current flow, capacitor C1 discharges through grid resistor R1, setting up a voltage drop across this resistor as shown. The net result is that we have an audio signal voltage appearing across the grid capacitor and grid resistor. This will cause the grid potential to vary at an audio rate so the tube now acts like a triode audio amplifier and amplifies this audio signal.

The grid-leak detector was quite widely used in the early days of radio, but it has disappeared almost entirely in favor of the diode detector. However, as you can see, the operation is similar to that of a diode detector followed by a triode audio amplifier.

SUMMARY

In this section of the lesson you have seen examples of both detectors and rectifiers. You have learned that a detector is a rectifier inasmuch as it operates on the principle of allowing current to flow through it in only one direction. There is a great deal of similarity between the operation of a detector and that of a rectifier. However, a rectifier is used to convert ac power to dc power where a detector is designed primarily to extract information from an rf carrier signal.

The half-wave rectifier operates on only one half cycle, whereas the full-wave rectifier operates on both half cycles, producing two pulses for each ac power-line cycle.

The diode detector is the most widely used detector in modern electronic equipment. As the amplitude of the signal applied to the diode detector varies, the current flowing through it varies. This causes the voltage across the diode load resistor and capacitor to vary at a rate that follows the intelligence superimposed on the rf signal.

The grid-leak detector is an example of a triode type detector. Its operation is similar to that of a diode detector followed by a triode audio amplifier.

SELF-TEST QUESTIONS

(v) On what principle do detectors and rectifiers operate?

(w) If a half-wave rectifier circuit is operated from a 60-cycle power line, how many current pulses per second will be fed to the filter network?

(x) How many pulses per second will the filter network receive from a full-wave rectifier circuit operating on a 60-cycle power line?

(y) What is the advantage of a full-wave rectifier over a half-wave rectifier?

(z) Draw a schematic diagram of a diode detector circuit.

(aa) What causes the amplitude of the pulses flowing through a diode detector to vary?

(ab) In the grid-leak detector, where does rectification occur?

(ac) To what type of circuit can we compare the grid-leak detector?

Oscillators

One of the most important uses of vacuum tubes is in oscillator circuits. An oscillator is a stage that generates its own signal. Without oscillators, the entire field of electronics would be extremely limited.

In communications, vacuum tubes are used in oscillator circuits to generate radio-frequency signals. Although it is possible to generate ac by mechanical means, there is a limit to how high a frequency can be generated. To generate signals of a very high frequency, electronic means rather than mechanical means must be used.

Practically all oscillators work on the same basic principle: part of the signal from the output of the stage is fed back to the input. The signal fed back to the input is called a feedback signal, or simply feedback. The feedback must be in phase with the signal in the input in order to reinforce it, so the stage can generate an ac signal. Actually, this stage simply converts the dc supplied by the power supply to ac. The exact frequency of the ac signal depends upon the circuit and the value of the components used in the circuit.

HARTLEY OSCILLATORS

Fig. 17 shows an oscillator circuit called a Hartley oscillator. In this circuit, energy is fed from the plate of the tube through C2 to coil L1. This energy is fed through the lower half of the coil to ground. The energy, in flowing through the lower half of L1, sets up a magnetic field which cuts the turns of the upper half of L1 and induces a voltage in it. This voltage is applied between the grid of the tube and ground and produces additional current flow in the plate circuit which will set up a field that will reinforce the signal in the grid circuit still further.

The coil that is marked RFC and is located in the plate circuit of the tube is a radio-frequency choke. It is put in the plate circuit to act as a high impedance to the flow of signal current and thus keep signal currents out of the power supply and force them through capacitor C2 to coil L1.

One of the interesting characteristics of an oscillator circuit is that it develops its own bias. The energy fed from the plate into L1 is of sufficient magnitude to produce a strong enough field to induce a high enough voltage in the upper half of the coil to drive the grid of the tube positive. When this happens, the grid will attract electrons; these electrons will charge the grid capacitor C1 with the polarity shown on the diagram. During the rest of the cycle, when the grid is negative, capacitor C1 discharges through grid resistor R1 and sets up a voltage drop across this resistor, as shown in Fig. 17.

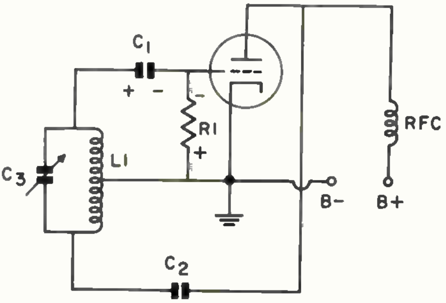

Fig. 17. A Hartley oscillator circuit.

Thus, the grid of the tube is maintained at a negative potential with respect to the cathode. If the amount of feedback from the plate circuit to the grid circuit is increased, the grid will be driven even more positive, charging capacitor C1 still higher, which will increase the bias on the grid of the tube. This in turn will automatically tend to reduce the plate current flowing through the tube. This automatic action tends to adjust the plate current of the tube and maintain it at a nearly constant value.

The frequency at which the circuit will oscillate will be determined primarily by the inductance of L1 and the capacity of C3. This coil and capacitor form a parallel resonant circuit. Changing the value of these components will change the frequency of oscillation.

COLPITTS OSCILLATORS

Another type of oscillator, the Colpitts oscillator, is shown in Fig. 18. Here the feedback is controlled by a capacitive voltage-divider network consisting of C3 and C4. Bias for this stage is produced by grid capacitor C1 and grid resistor R1 as in the Hartley oscillator.

The frequency at which this circuit will oscillate depends primarily on the inductance of coil L1 and the capacity of capacitors C3, C4, and C5. Capacitor C5 is variable; the frequency of the oscillator can be adjusted by changing the capacity of C5. Increasing the capacity will cause the oscillator to operate at a lower frequency; decreasing the capacity will cause the oscillator to operate at a higher frequency.

The output of the Colpitts oscillator as well as that of the Hartley oscillator is a sine wave. However, not all oscillators have sine-wave outputs. In some cases an output signal other than a sine wave is desired. An example of an oscillator that produces a signal other than a sine wave is the multivibrator.

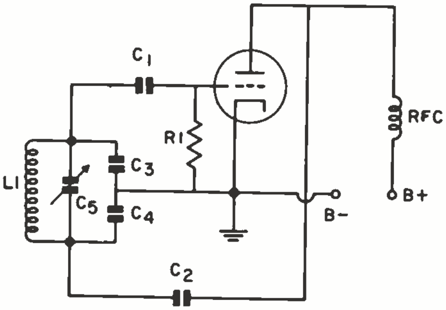

Fig. 18. A Colpitts oscillator circuit.

MULTIVIBRATORS

The multivibrator is widely used in television and in many industrial applications. The output from this type of oscillator is not a sine wave, in fact it is almost a square wave.

The schematic diagram of a typical multivibrator is shown in Fig. 19. This type of multivibrator is called a plate-coupled multivibrator

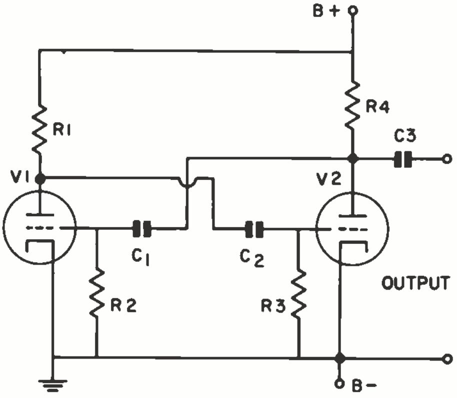

Fig. 19. A plate-coupled multivibrator.

because the energy necessary for oscillation is fed between the tubes from the plate of each tube to the grid of the other tube.

The multivibrator is a rather interesting circuit. Let us see how it works. When the multivibrator shown in Fig. 19 is first turned on, the cathodes of the tubes will not immediately be hot enough to emit electrons, so no current will flow through either tube. Meanwhile the power supply will heat and begin to operate so there will be B+ voltage available. Since there is no current flow through the tubes, there will be no voltage drop across R1 or R4 due to plate current flowing through them. Therefore C1 and C2 will start to charge to a voltage equal to the full power-supply voltage.

To understand this action better, look at Fig. 20. We have shown just the parts involved. The parts shown at A could be drawn as in B; and those shown at C could be drawn as at D. As you can see, when the B supply is operating, C1 will charge through R2 and R4; and C2 will charge through R3 and R1. As these capacitors are charging, the tubes V1 and V2 will be heating and will start passing current.

When V1 and V2 start to pass current, there will be plate current flow through R1 and R4 that will result in voltage drops across these resistors. If C1 and C2 have charged to a voltage higher than the voltage between the plates of the tubes and ground, they must now discharge through R2 and R3 respectively. This will result in a voltage across these resistors that will make the grid end of the resistors negative. The exact voltage will depend on how big a charge the capacitors must get rid of. This in turn will depend on how much current flows through the tubes. It is very unlikely that the two tubes will pass exactly the same current, so one of the capacitors will be discharging at a faster rate than the other, and this will result in a higher negative voltage appearing across one grid resistor than the other.

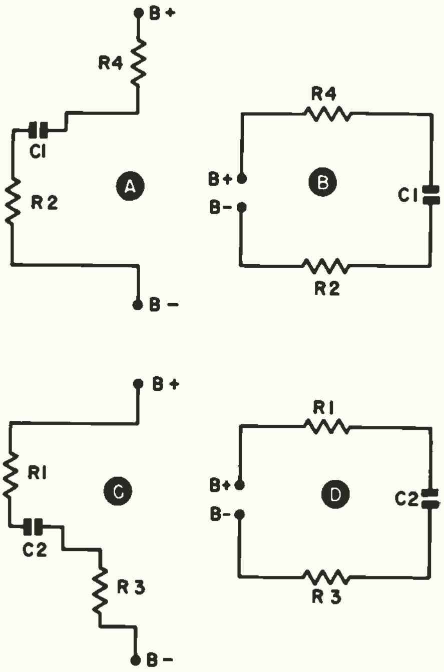

Fig. 20. When the multivibrator shown in Fig. 19 is first turned on, C1 and C2 will charge. This part of the circuit is shown here.

Let's assume that the current through V1 is higher than the current through V2. This will mean that there will be a higher voltage drop across R1 than across R4. C2 will be discharging at a fairly high rate through R3, which will produce a high negative voltage on the grid of V2. This negative voltage on the grid of V2 will reduce the plate current through this tube still further, so the voltage drop across R4 will decrease. C1 will now start to charge to the higher voltage between the plate of V2 and ground. To charge, the capacitor will draw electrons through R2. These electrons will flow through R2 in a direction that will make the grid end of this resistor positive. This positive voltage on the grid of V1 will cause V1 to draw still more current. The higher current through V1 will result in more current flowing through R1, which will cause a greater voltage drop across the resistor. The voltage between the plate of V1 and ground will therefore drop, and capacitor C2 will have to discharge still further. In discharging it will make the grid of V2 even more negative, so the flow of plate current through this tube will be completely cut off.

With plate current through V2 cut off, C1 will eventually charge up to a voltage equal to the B supply voltage. When the capacitor is charged to this voltage, the charging current through R2 will stop flowing, and the positive voltage on the grid of V1 will disappear. When this happens, the current flowing through V1 will drop, causing the voltage drop across R1 to decrease. This will mean that the voltage between the plate of V1 and ground will increase. As soon as this happens, C2 will begin to charge through R3, putting a positive voltage on the grid of V2. Almost instantly V2 will start conducting heavily; the plate voltage on V2 will drop, and capacitor C1 will start to discharge through R2, placing a high negative voltage on the grid of V1 and cutting off the flow of plate current through this tube. When this happens, current will stop flowing through R1, so there will be no voltage drop across this resistor and the voltage between the plate of V1 and ground will jump up to a value equal to the supply voltage. C2 will now have to charge to an even higher voltage, so the grid of V2 will be driven highly positive by the current flowing through R3 to charge this capacitor.

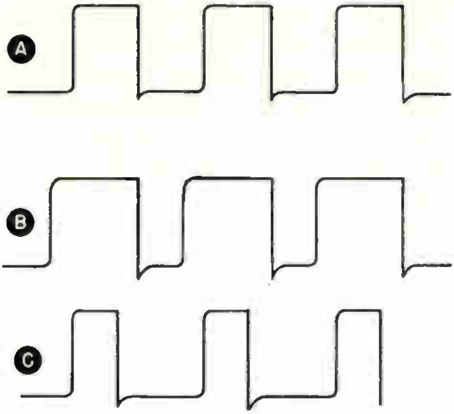

Fig. 21. Output of symmetrical and non-symmetrical multivibrators.

This action of first one tube conducting and cutting off the flow of plate current through the other, and then reversing so that the other tube conducts and cuts off the first tube, will continue as long as power is applied to the oscillator.

Notice that in the multivibrator two tubes are used, whereas in the oscillators we studied before only one tube was needed. In actual practice a dual triode tube that has two separate triodes in the one glass envelope is often used in a multivibrator circuit. Even though this may look like only one tube, we have two-tube action.

The frequency of oscillation will depend primarily on the values of C1-R2 and C2-R3.

If the combination of R2 and C1 has a time constant equal to that of

R3 and C2, the multivibrator is called a symmetrical multivibrator. Each tube will conduct and be cut off for the same length of time, and the output will look like Fig. 21A. However, if the time constant of C2 and R3 is longer than that of C1 and R2, V2 will be cut off for a longer time than V1, and the output will be like Fig. 21B. On the other hand, if the time constant of C1 and R2 is longer than that of C2 and R3, V1 will be cut off longer than V2, and the output will be like Fig. 21C.

The plate-coupled multivibrator is only one type of multivibrator; there are several other types that you will study later.

SUMMARY

Oscillators are important to the electronics technician. You will find them in radio and TV receivers. Every superheterodyne has a local oscillator. Television receivers have oscillators similar to the multivibrator to generate the signals that move the electron beam over the face of the picture tube.

The Hartley oscillator and the Colpitts oscillator both generate a sine-wave output. In the Hartley oscillator, feedback is obtained by inductive means, whereas in a Colpitts oscillator feedback is obtained by means of a capacitive voltage divider. The two oscillators are otherwise basically similar.

The multivibrator is an RC coupled oscillator. Its output is not a sine wave. It is useful in TV receivers and in many industrial applications. Two tubes are needed in a multivibrator circuit. The two conduct alternately; when the first tube is conducting, the second is cut off, and when the second tube is conducting, the first is cut off.

SELF-TEST QUESTIONS

(ad) On what principle do oscillators operate?

(ae) Draw a schematic diagram of a Hartley oscillator.

(af) Across what part is grid bias for the Hartley oscillator developed?

(ag) In the Hartley oscillator circuit shown in Fig. 17, which two parts primarily control the oscillator frequency?

(ah) What controls the feedback in the Colpitts oscillator circuit shown in Fig. 18?

(ai) What parts primarily determine the oscillator frequency in the Colpitts oscillator shown in Fig. 18?

(aj) What type of output signal is obtained from the Hartley and Colpitts oscillators?

(ak) What type of output signal is obtained from a multivibrator?

(al) What parts primarily control the frequency of the multivibrator shown in Fig. 19?

(am) What is the name given to the particular multivibrator shown in Fig. 19?

A Complete Superheterodyne Receiver

Now let us see how the different circuits are put together in a radio receiver. We have already mentioned that modern radio receivers use what is called the superheterodyne circuit. A block diagram of a typical superheterodyne receiver is shown in Fig. 22. In Fig. 22A we have shown the various functions performed in the receiver. The block diagram is often drawn like the diagram in B because the mixer and oscillator are usually combined in one tube and the second detector and first audio stage are also combined in the tube. Therefore the diagram, shown in Fig. 22B, shows in block diagram form the functions performed by the various tubes.

In the superheterodyne receiver, the signal is picked up by the antenna and is fed to the first stage which is the mixer stage as shown in Fig. 22A. At the same time, a signal from a local oscillator is also fed to the mixer stage. The local oscillator always operates at a fixed frequency above the frequency to which the mixer is tuned. In modern radio receivers the oscillator is usually operated 455 kHz above the incoming signal. In the mixer circuit the in-

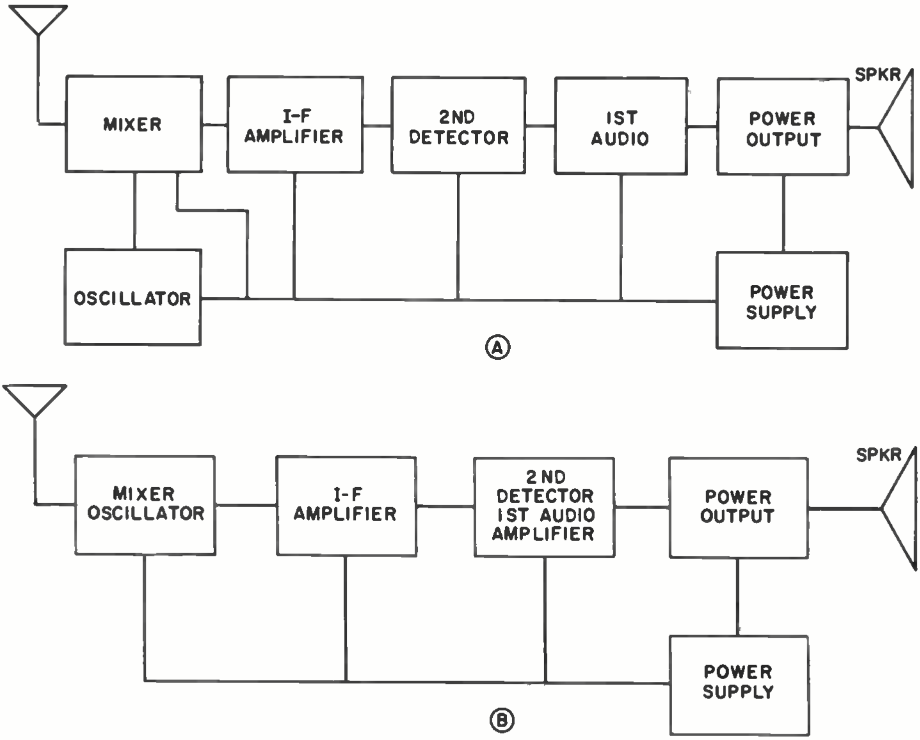

Fig. 22. A block diagram of a 5-tube superheterodyne receiver.

coming signal is mixed with the signal produced by the local oscillator. This mixing of the two signals results in two new signal frequencies appearing in the output of the mixer, one equal to the sum of the local oscillator and the incoming signal frequency, and the other equal to the difference between the two frequencies.

We mentioned that the oscillator is operated 455 kHz above the incoming signal frequency. Therefore the difference between the incoming signal frequency and the oscillator signal frequency will be 455 kHz.

The second stage in the superheterodyne is a radio-frequency amplifier stage called the i-f amplifier. It is tuned to the i-f frequency. which is equal to the difference between the frequency of the incoming signal and the frequency of the local oscillator in the receiver.

The i-f amplifier is what is called a fixed-frequency amplifier. In other words, it is always tuned to the same frequency, which in most cases is 455 kHz. Because the amplifier is tuned to a fixed frequency, it is possible to design a stage with a very high gain without running into any problems such as instability or oscillation. Therefore the i-f amplifier amplifies the i-f signal substantially.

The i-f signal is then fed to the stage called the second detector, which is usually a diode detector. Here the intelligence is separated from the radio-frequency carrier. The intelligence signal is the audio signal used to modulate the carrier signal at the transmitter. The audio signal produced by the second detector is fed to the first audio stage where it is amplified and finally fed to the output stage, which is a power amplifier that produces the power necessary to drive the loudspeaker.

A schematic diagram of a superheterodyne receiver is shown in Fig. 23. We will not go through this receiver stage by stage to see how each stage works. We have already studied most of these stages in this lesson, so we will now concentrate on taking up a few additional details and also seeing how the stages are used together.

THE MIXER-OSCILLATOR

The tube used in the mixer-oscillator stage is a 12BE6 tube marked V1. This tube is a pentagrid converter. Pentagrid means five grids; the tube is called a converter because it is designed for service as a frequency converter, which is what the mixer-oscillator stage is often called.

In this tube the first and second grids in conjunction with the cathode act like a triode tube. The first grid is the control grid and the second grid acts as the plate of the triode section of the tube. Thus the cathode, the first grid, and the second grid are used as an oscillator. This oscillator modulates the stream of electrons flowing from the cathode to the plate of the tube. The incoming signal picked up by the loop antenna is fed into the No. 3 grid. This signal also modulates the electrons flowing from the cathode to the plate of the tube so that the resultant flow of electrons from the cathode to the plate of the tube will be modulated both by the signal produced by the local oscillator and by the incoming signal. This modulation will produce a signal with a frequency equal to the difference in the frequency of the

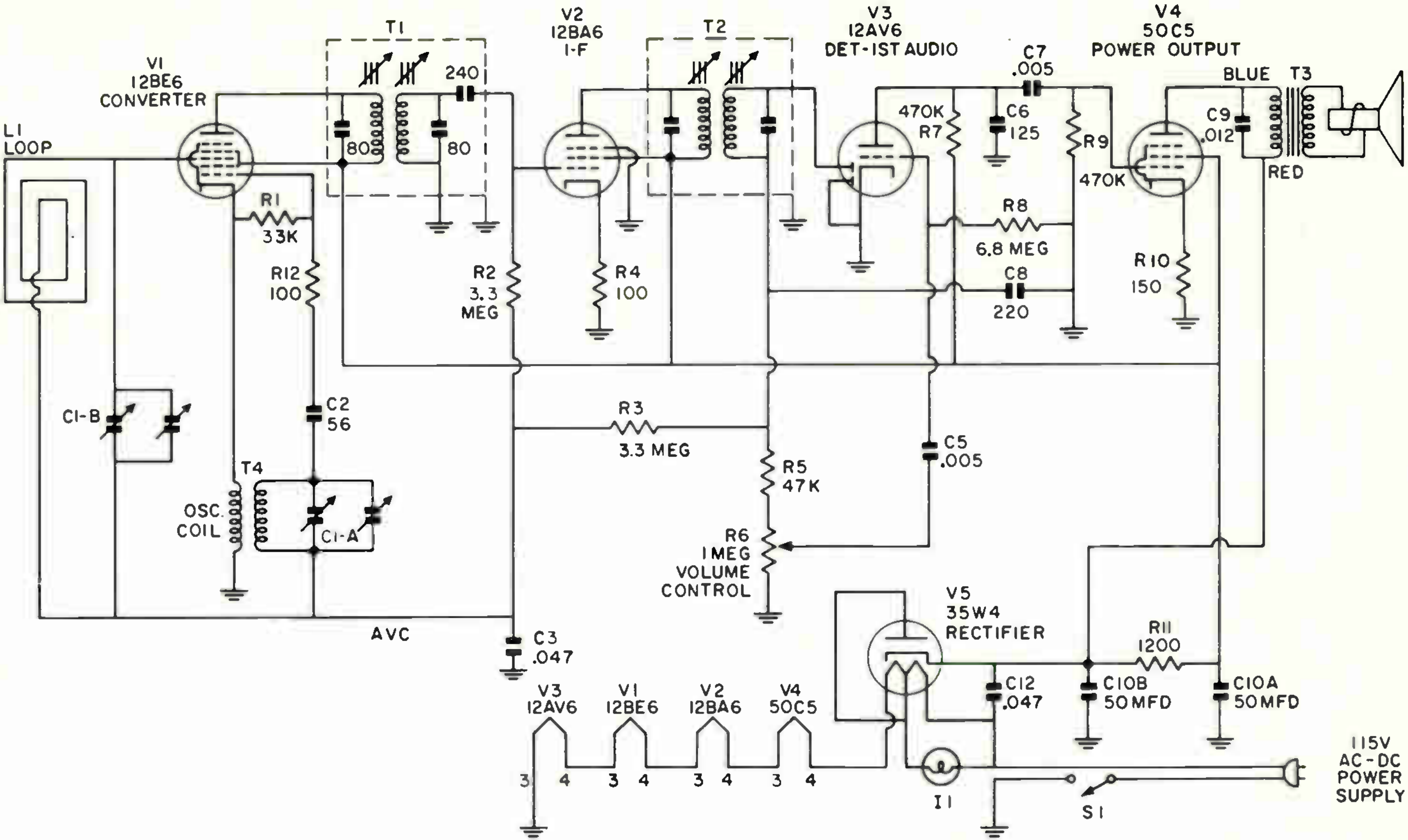

Fig. 23. Schematic diagram of a complete superheterodyne receiver.

two signals which will be the i-f signal, in addition to a signal equal to the sum of the frequencies of the two signals.

The primary winding of the transformer T1 and the capacitor connected across it form a parallel resonant circuit. This circuit is tuned to resonance at the difference frequency produced in the converter stage. Therefore it acts as a high resistance at this frequency, while at the same time it acts as a low impedance at the frequency of the incoming signal, the frequency of the local oscillator, and the frequency equal to the sum of the two frequencies. Thus in the parallel resonant circuit we will have a high circulating current having a frequency equal to the difference frequency. The other three frequencies appearing in the plate circuit of the mixer tube will produce little or no current flow in the resonant circuit.

THE I-F AMPLIFIERS

The secondary of T1 is inductively coupled to the primary. Thus a voltage will be induced in series with the secondary winding. The secondary winding of the transformer is tuned to resonance by the capacitor connected across it, and this coil and capacitor form a series resonant circuit. In a series resonant circuit there will be a high circulating current, and a resonant voltage step-up. This voltage is applied between the grid and cathode of the i-f amplifier.

The difference-frequency signal applied between the grid and cathode of the i-f amplifier is amplified by this stage. In the plate circuit of this tube, which is a conventional pentode rf amplifier, there is another parallel resonant circuit. This is made up of the primary winding of T2 plus the capacitor connected across it. Again, this transformer acts as a high resistance at the difference frequency and a low impedance at other frequencies.

Before leaving the i-f stage, notice the lead marked AVC. AVC is an abbreviation for automatic volume control. A variable voltage is applied to this lead, which in turn is connected to the grid of the i-f tube V2 through the 3.3-megohm resistor R2. The voltage is also applied to the grid of the mixer tube through the loop antenna.

The voltage that is fed to the grids of these tubes will depend upon the strength of the signal picked up from the station. If the signal is very strong, a fairly high negative voltage is fed to the grids of these tubes and this voltage reduces the gain of the stages. If the signal is weak, the negative voltage drops almost to zero so that the two stages operate at maximum gain. We will see how this voltage is developed when we study the second detector used in this receiver.

The tube used in the i-f stage of a modern superheterodyne receiver is usually what is called a remote cut-off type. A remote cut-off tube is a tube with a specially made control grid. The grid is designed so that it takes a very high negative voltage to completely cut-off the flow of plate current.

In the tubes we have discussed so far, the grid wires have been evenly and rather closely spaced. The plate current flow in a pentode tube that is made in this way can be cut off with a fairly low negative voltage applied to the grid of the tube. This type of tube is called a sharp cut-off tube. If however, instead of spacing the grid wires evenly, we space them so that they are close together at the ends but spaced quite widely apart in the middle as shown in Fig. 24, a much higher negative voltage must be applied to the grid of the tube before the plate current can be reduced to zero. As we begin to apply negative voltage to the grid of the tube to cut off the flow of plate current, the grid wires at the ends are able to cut off the flow of plate current through them, but because of the wide spacing in the center part of the grid, electrons will still travel from the cathode to the plate of the tube. In order to cut off the flow of plate current with this type of grid structure, a much higher negative grid voltage is required than with the sharp cut-off tube.

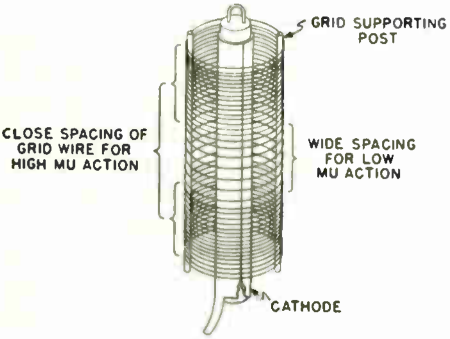

Fig. 24. The grid of a remote cut-off type pentode. Here the spacing between the grid wires is greater at the center of the grid than at the ends.

The remote cut-off tube is ideally suited for i-f amplifiers where avc is used. However, this type of tube usually does not have quite as high a gain as a sharp cut-off tube. A compromise between the sharp cut-off and the remote cut-off tubes is the semi-remote cut-off tube. In this type of tube, the spacing between the grid wires in the center of the tube is not quite as wide as the spacing between the grid wires in the remote cut-off tube.

THE DETECTOR - FIRST AUDIO STAGE

In our superheterodyne receiver the i-f signal is fed from the i-f stage to the second detector. The secondary of the i-f transformer forms a series resonant circuit with a capacitor connected across it. One end of the secondary is connected directly to the plate of the diode detector and the other end is connected to the diode load, which is made up of the 47K-ohm resistor R5 and 1-megohm volume control R6. These two resistors are in parallel with the diode load capacitor C8. You already know how a detector works and how an audio voltage will appear across the diode load resistors R5 and R6 and the diode load capacitor C8.

The i-f signal flowing through the detector can flow in only one direction with the result that there will be a series of pulses at the detector output which will charge the diode capacitor C8. The charge across this capacitor will depend upon two things, the audio signal and also the strength of the signal being received. By connecting a filter network consisting of a resistor and a capacitor such as R3 and C3 across this capacitor a dc voltage can be obtained across C3 that will depend upon the strength of the incoming signal. Now let's see where this voltage comes from.

We have a series of pulses flowing through the diode, charging capacitor C8. The amplitude of these pulses, and hence the voltage across C8, depends on the audio signal and the strength of the signal being received. C8 discharges through R5 and R6, producing a voltage having a polarity such that the junction of R5 and the i-f transformer is negative. This voltage also will depend on the audio signal and the strength of the signal being received.

This voltage also is across the combination of R3 and C3 in series. However, R3 and capacitor C3 form a voltage divider network. The resistance of R3 is much higher than the reactance of C3. Therefore most of the audio signal appearing across the two will be dropped across R3 so that the voltage across C3 will be almost pure dc and its strength will depend upon the strength of the incoming signal. This voltage is then fed to the avc line and used to control the gain of the mixer and i-f tubes. If the strength of the signal being picked up is strong, then a fairly high negative voltage is developed across C3, whereas, if the signal is weak, the voltage across C3 will be low. This voltage is used to control the gain of the mixer and i-f stages so they operate at maximum gain when a weak signal is being received, and at reduced gain when a strong signal is being received.

AVC is used in most modern radio receivers to regulate the gain of the set, so that as you tune across the broadcast band from one station to another, they all come in at approximately the same volume. Actually, this system is an automatic gain control rather than an automatic volume control, but when the scheme was first introduced manufacturers called it an automatic volume control because they felt that this would have more appeal to the public than the name automatic gain control. The name automatic volume has stuck, but the same system used in television receivers is called automatic gain control.

The tube used in the second detector-first audio stage is a combination tube. The tube contains two diodes and one triode. Only one of the diodes is used in the detector circuit; the other diode plate is unused and simply connected to ground and to the cathode. The triode section is used as the first audio stage. You will notice that the diode load is actually made up of two resistors. The 47K resistor R5 is only one twentieth of the size of R6 so most of the voltage will appear across R6. R6 is a potentiometer. The position at which the center tap connects to the resistor can be controlled by rotating the control shaft on the potentiometer. By moving this tap up and down the resistor, the amount of audio signal fed to the first audio stage can be varied. This control is called a volume control since it will vary the volume or output from the sound system in the receiver. The audio signal is then fed through coupling capacitor C5 to the grid of the first audio tube.

The first audio tube uses a bias system that we have not discussed previously. Notice that the cathode of the tube is connected directly to ground, and the grid resistor R8 is a 6.8-megohm resistor. You already know that some of the electrons leaving the cathode of the tube and travelling toward the plate will accidentally strike the grid of the tube. The number striking the grid is quite small, and these electrons flow through the grid resistor back to ground and from there back to the cathode of the tube. In most stages the grid resistor is kept low enough so the number of electrons flowing through it do not produce an appreciable voltage. However, by using a large value of grid resistor, a voltage can be developed across it to bias the tube. This type of bias is usually called "convection" bias and is frequently used in the first audio stage of modern radio receivers.

THE OUTPUT STAGE

The output stage in most modern receivers is either a pentode or a beam power tube. The tube is operated as a Class A amplifier.

In this receiver, the signal from the plate of the first audio stage is coupled to the grid of the output stage through capacitor C7. R9 is a grid leak resistor and R10 is the cathode bias resistor. The cathode bypass capacitor is omitted from this stage to improve the frequency response of the stage. You will see in a later lesson exactly why this happens.

The loudspeaker is a permanent-magnet dynamic speaker. This speaker is coupled to the output tube by means of transformer T3, which is called the output transformer. We have already studied output transformers and know that they are impedance-matching devices designed to match the low impedance speaker to the high impedance of the plate of the output tube in order to get as high a power transfer as possible.

There are a number of different types of tubes used as output tubes, but in general the circuit is similar to the one shown in Fig. 23, although the values of the components used in the circuit may vary slightly with different tubes.

THE POWER SUPPLY

The only section of the receiver left to discuss is the power supply. This is a universal ac-dc type of power supply using a half-wave rectifier similar to the one shown in Fig. 12.

The Plate Supply.

Notice that the plate voltage for the output tube is taken directly from the cathode of the rectifier tube through the primary of the output transformer instead of from the output of the filter network. We can do this because the plate current flowing in a pentode or beam power tube depends primarily on the screen voltage, and the plate voltage has little or no effect on it. Thus the ac ripple applied to the plate of the tube will not cause any appreciable hum current to flow through the tube and the primary of the output transformer. The output tube alone will draw as much current as all the rest of the tubes in the receiver. If we take the plate supply of the output tube directly from the cathode of the rectifier, we can use a resistor instead of a choke in the filter network, as we have done here-R11 in Fig. 23.

If we connected the plate of the output tube to the other side of the filter network, we would have to use a choke, because the high current drawn by the output tube through a resistor would cause such a high dc voltage drop that the output voltage for the rest of the plates would be too low. A choke has a high ac reactance, so it would filter any ripple voltage, but it has a low dc resistance, so the dc voltage drop across it would be lower.

The advantage of using a resistor in place of a choke is simply one of economy. A resistor is much cheaper than a filter choke. As long as the current through the resistor can be kept to a reasonably low value, the dc voltage drop across the resistor will not be too great. The resistor will form a voltage divider network with the output filter capacitor so that the hum voltage from the cathode of the rectifier will be reduced enough to provide suitably pure dc for the operation of the receiver. The plate and screen voltages for the rest of the tubes and the screen voltage for the output tube are obtained from the output of the filter network. These voltages will be much better filtered than the voltage supplied to the plate of the output tube. If these tubes, particularly the first audio tube or the screen of the output tube, were operated directly from the cathode of the rectifier tube there would be an extremely loud hum produced by the speaker.

The Heater Circuit.

The heaters of the various tubes in this receiver are connected in series, and the series circuit is connected directly across the power line. The tubes are designed so that they all require the same operating current. The voltage requirements for the various tubes are different. The 35W4 rectifier tube requires a heater voltage of 35 volts. The 50C5 output tube requires a heater voltage of 50 volts. Each of the other tubes requires a heater voltage of 12.6 volts. If you add these voltages together, you will find that the total is 122.8 volts. In actual practice, these tubes can be operated from a line voltage of anywhere between about 110 volts and 125 volts, and give satisfactory performance. Notice the pilot light marked I1 on the diagram. The heater of the 35W4 is tapped, and the pilot light is connected in parallel with part of the heater to get the voltage needed to operate the light.

Notice that 12-volt heaters are closer to the side of the power line that connects to B-, so that the voltage between these heaters and B- is maintained as low as possible.

The first audio tube is almost always connected at the end of the string so that one side of its heater is connected to B-. This keeps the potential between the cathode and heater of this tube as low as possible. This particular tube is more susceptible to hum pickup than are the other tubes in the receiver. The arrangement used in this receiver is pretty standard for this type of set. If you trace the heater circuit in an ac-dc receiver starting at the side of the power line that connects to B-, you will find the tubes connected in the following order: the first audio-second detector; the mixer oscillator; the i-f amplifier; the power output tube, and finally the rectifier.

Since the tube heaters in this receiver are connected in series, if any one of the heaters burns out, none of the tubes will light. This is probably the most common defect you will find in ac-dc receivers. Keep this point in mind. If you are asked to service a small ac-dc receiver and you find that none of the tubes light, look for a tube with an open heater. The chances are that replacing this tube will clear up the trouble.

SUMMARY

In this section of this lesson we have shown how the various stages that you have studied previously are put together to form a complete receiver. From this discussion you can see that a complete radio receiver is simply made up of a number of different stages, each performing the task for which it was designed. Complex electronic equipment is made up in the same way; it is made of a number of simple separate stages designed to work together.

There are a number of things that we have not discussed about these various stages, but we will discuss them in more detail in later lessons. At present you should have a general understanding of how each stage works and how they are put together to form a complete receiver.

SELF-TEST QUESTIONS

(an) To what stage is the signal from the antenna fed in a typical five-tube superheterodyne receiver?

(ao) In a modern superheterodyne receiver is the oscillator frequency higher or lower than the frequency of the incoming signal?

(ap) If you tune a superheterodyne receiver to a broadcast station operating on 1500kc, and the i-f amplifier operates on a frequency of 456kc, at what frequency must the local oscillator in the receiver be operating?

(aq) In the 12BE6 tube used in the circuit shown in Fig. 23, which grid acts as the plate of the oscillator tube?

(ar) In the i-f transformer T1 in Fig. 23, both the primary and secondary circuits are tuned to resonance. Are these circuits series-resonant circuits or are they parallel-resonant circuits?

(as) What is meant by a remote cut-off tube?

(at) In the second detector in the circuit shown in Fig. 23, across what part is the audio signal voltage developed?

(au) How is bias for the first audio stage in the circuit shown in Fig. 23 developed?

(av) What class of power amplifier is used in the circuit shown in Fig. 23?

(aw) In the circuit shown in Fig. 23, the heaters of all the tubes are connected in series across the power line. If you were called on to service a receiver of this type and saw that none of the tubes were lighting, what type of trouble would you look for?

Amplifier Variations

We have already mentioned that there are three basic types of amplifiers, the grounded-cathode, the grounded-grid, and the grounded-plate. All the amplifiers you have studied so far have been grounded-cathode amplifiers. Most of the amplifiers you will encounter will be the grounded-cathode amplifiers, but the other two types are also important. They have some special characteristics that are very useful in certain applications. The grounded-grid amplifier is widely used as the rf amplifier in VHF tuners of TV receivers. It is also quite widely used in transmitting equipment. The cathode-follower, which is the more frequently used name for the grounded-plate amplifier, is widely used in industrial applications, and also it has recently been used in a large number of color TV receivers. The cathode-follower is particularly useful as an impedance-matching device to match a high-impedance circuit to a low-impedance circuit.

In this section of this lesson you will study some of the important characteristics of all three types. You will see how these amplifiers differ from each other and see some examples of grounded-grid and grounded-plate amplifier circuits.

THE GROUNDED-CATHODE AMPLIFIER

As we mentioned, the amplifiers we have been studying have all been grounded-cathode amplifiers. We have repeated the basic grounded-cathode circuit shown in Fig. 1 as Fig. 25. Notice that the signal is applied between the grid and cathode of the tube; the cathode is operated at signal ground potential, and the load is placed in the plate circuit. The output signal is developed across the load, so in this circuit it is developed between the plate of the tube and ground. Remember that the end of the load that is connected to the B supply is at ground potential as far as the signal is concerned.

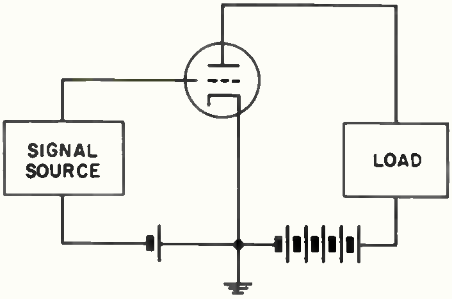

Fig. 25. The grounded-cathode amplifier shown in Fig. 1 is repeated here for your convenience.

Circuit Characteristics.

You already know how the grounded-cathode circuit amplifies a signal, so we will not go through an explanation of how this circuit works. Instead we will discuss some of the important characteristics of this type of circuit.

One important characteristic of this type of amplifier is that the output signal is greater than the input signal; in other words, the stage is capable of amplifying. The actual gain of the stage is equal to the ratio of the output voltage divided by the input voltage. The gain obtained from this type of stage may be quite low, sometimes as low as only two or three, or it may be quite high, sometimes as high as two hundred or more. The exact gain will depend on the tube used in the amplifier and the value of the components used with the tube.

Another important characteristic of this type of stage is that there is a phase shift of a half-cycle or 180° between the input and output signals. This means that when the input signal drives the grid in a positive direction, the output signal between the plate and ground will be going in a negative direction. Similarly if the grid is being driven negative, the output signal will be going positive.

Two other important characteristics are the input and output impedances of the stage. The input impedance is important because it tells you how the stage will load the signal source. The output impedance is important because it gives an indication of the type of load that must be connected in the output circuit in order to obtain proper results from the stage.

You will remember that in a Class A voltage amplifier the tube is biased so that it operates on the mid-point of its characteristic curve. The input signal is not strong enough to drive the grid positive, so there will be no grid current flow. Thus the input circuit of a Class A voltage amplifier is a high-impedance circuit. This is important because it tells us that this type of stage will take little or no power from the source driving the stage.

In a Class B or Class C power amplifier the grid is driven positive, so grid current will flow. Thus these stages have a comparatively low input impedance and will require power from the driving stage.

We can summarize the input characteristics of the grounded-cathode amplifier as follows: Voltage amplifiers and Class A power amplifiers draw no grid current, and hence have a high input impedance. Class B and Class C power amplifiers draw grid current, require power from the driver stage, and have a fairly low input impedance.

The grounded-cathode amplifier also has a fairly high output impedance. The load is placed in the plate circuit of the tube, and the output is developed across this load. If the load impedance is low, the output will be low.

THE GROUNDED-PLATE AMPLIFIER

The grounded-plate amplifier is more commonly called a cathode follower. The load in this type of circuit is connected in the cathode circuit between the cathode of the tube and ground. A block diagram of this type of amplifier is shown in Fig. 26.

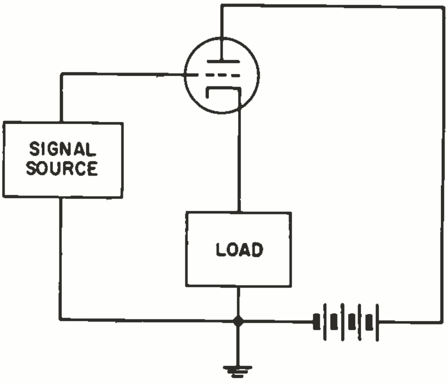

Fig. 26. A grounded-plate or cathode-follower circuit.

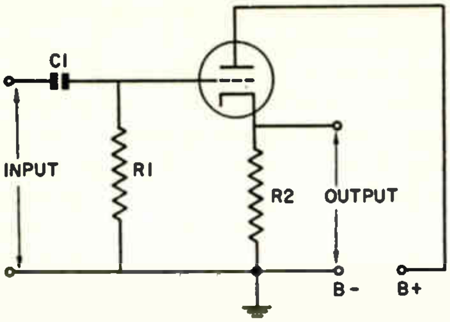

Fig. 27. Schematic diagram of a cathode follower stage.

Notice that the signal is applied between the grid of the tube and ground, as in the grounded-cathode amplifier, but the difference between the two is in the placement of the load.

Putting the load in the cathode circuit completely alters the characteristics of the amplifier. Let us study the operation of a typical cathode follower such as the one shown in schematic form in Fig. 27 to see why this type of amplifier is so different from the grounded-cathode type.

Capacitor C1 is used in the input circuit to isolate the grid circuit of the stage from the signal source and to keep any dc that may be present at the signal source away from the grid of the tube. Resistor R1 is the grid resistor and is placed in the grid circuit to act as a grid leak and provide a path back to the cathode for any electrons that accidentally strike the grid of the tube. The load is R2. It is placed in the cathode circuit of the tube between the cathode and B-. The plate of the tube is connected directly to B+, and since B+ is at ground potential insofar as the signal is concerned, the amplifier is a grounded-plate amplifier.

The operation of this type of amplifier is quite different from that of the grounded-cathode amplifier. When the input signal drives the grid in a positive direction, the current flowing from the cathode of the tube to the plate will increase. This will cause the voltage across the cathode resistor R2 to increase because the plate current flows through this resistor. However, notice that the input signal is applied between the grid of the tube and ground. The actual voltage that will control the flow of plate current through the tube is the voltage between the grid and cathode. If the grid voltage goes positive, the increase in plate current will cause the voltage between the cathode and ground to increase and become more positive. In other words, the positive voltage at the grid produces a more positive voltage at the cathode. This subtracts from the signal voltage so that it reduces the net grid-to-cathode voltage. This means that we have a situation where the output signal being produced by the stage subtracts from the input signal and reduces the input to the tube. Thus the output signal must always be less than the input signal in this type of amplifier. Technicians say that the gain of the stage is less than one. If the output signal were greater than the input signal, it would completely cancel the input signal producing it.

You might wonder why the cathode follower would be of any use at all if the output signal is less than the input. The stage is useful for two reasons. First, the output signal is in phase with the input. This means that when the input signal swings positive, the output signal swings positive; and when the input signal swings negative, the output signal swings negative. There are some applications where it is important not to change the phase.

Another and more important use of the cathode follower is as an impedance-matching device. The cathode follower has a high input impedance, but because the load is in the cathode circuit, it has a low output impedance. Thus, if we have a high-impedance generator and want to connect it to a low-impedance load, we can use a cathode follower to match the two impedances.

Cathode followers are very useful in any application where it is important to isolate the load from the signal source. They are often found in the input of a cathode ray oscilloscope, which is a test instrument used in servicing many kinds of electronic equipment. The cathode follower is used in the input circuit to provide isolation between the circuit under test and the test instrument so that connecting the test instrument to the equipment does not affect the performance of the equipment.

THE GROUNDED-GRID AMPLIFIER

The grounded-grid amplifier is used in some special cases as a power amplifier. You will remember that we pointed out that when a triode tube is used as an rf amplifier, unless special precautions are taken, the tube will oscillate. This oscillation that occurred in a triode tube was one of the factors that led to the development of the tetrode tube. Remember that the screen grid was added to the tube in order to shield the grid from the plate and keep the energy fed from the plate back to the grid of the tube as low as possible.

In some circuits a triode tube will operate where a beam power tube or a pentode tube will not give satisfactory service. This situation is encountered at very high frequencies. It comes about because of the time it takes an electron to travel from the cathode of the tube to the plate. At very high frequencies a single cycle may take only a fraction of a millionth of a second. A half cycle will take only half this time. It could take the electrons longer than the time of one half cycle to travel from the cathode to the plate of the tube if the spacing between the cathode and plate were too great. The spacing between the cathode and plate in a beam power tube or a pentode is greater than in a triode because there must be room for the extra elements.

In higher-power amplifiers using beam power tubes with a high sensitivity, there will sometimes be oscillation because of energy getting through the screen from the plate of the tube to the grid. If the tube is a very sensitive tube, a small amount of energy getting through the screen may be enough to cause oscillation in the stage.

Oscillation in a triode stage or in a high-gain beam power stage can often be eliminated by using a grounded-grid circuit, because the grid is operated at ground potential. The signal is fed into the cathode circuit, and the grid, which is grounded, acts to shield the output circuit from the input circuit.

A simplified diagram of a grounded-grid amplifier is shown in Fig. 28. Notice that in this circuit the input is fed into the stage between the cathode and ground, and the grid

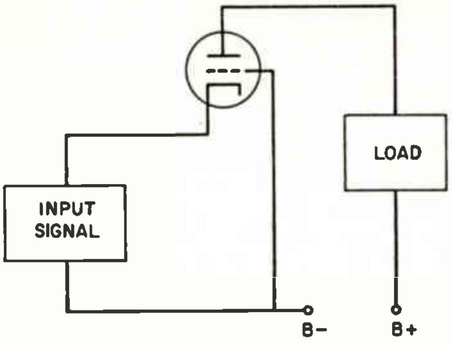

Fig. 28. Block diagram of a grounded-grid amplifier.

is operated at signal ground potential. The load is connected in the plate circuit of the tube as in the grounded-cathode amplifier.

The schematic diagram of a grounded-grid amplifier using a beam power tube is shown in Fig. 29. In this circuit the input signal is fed between the filament-type cathode and ground. The filament of the tube is isolated from ground by the two radio-frequency chokes, marked RFC1 and RFC2 on the diagram. These chokes are simply coils that have high inductive reactances at the operating frequency. Because they have high reactances, the filament cathode is isolated from ground insofar as the signal is concerned, while at the same time the chokes offer little or no opposition to the flow of dc or low-frequency ac used to heat the filament of the tube.

In this type of amplifier, if the incoming signal drives the cathode positive with respect to ground, it drives the cathode positive with respect to the grid, because the grid is connected to ground as far as the signal is concerned through capacitor C1, which has a low reactance at the signal frequency. If the cathode is driven positive with respect to the grid, it is the same as driving the grid negative with respect to the cathode, so the current flowing from the cathode to the plate of the tube will decrease. On the other hand, if the cathode is driven negative with respect to the grid, it is the same as driving the grid positive with respect to the cathode, so the plate current will increase.

Since both the grid and the screen grid of this tube are connected to ground as far as the signal is concerned, it will be almost impossible for any energy to get from the plate of the tube back into the input circuit. As long as energy cannot get from the plate circuit back into the input circuit, the stage will not oscillate.

It is not important to go into all the details of the grounded-grid amplifier at this time. The important thing for you to remember is the general configuration of the circuit. Remember that the signal is fed into the cathode circuit, and the load is connected into the plate circuit. Remember also that the big advantage of this type of circuit is that the energy fed from the plate circuit

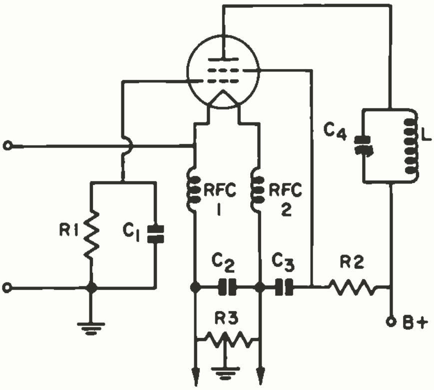

Fig. 29. Schematic diagram of a grounded-grid amplifier.

back into the input is low, so that the possibility of oscillation is remote.

SUMMARY

The important thing for you to remember from this section of the lesson is the general pattern of the circuit. Remember that there are three types of amplifier circuits: the grounded-cathode, the grounded-plate or cathode follower, and the grounded-grid amplifier. Most of the amplifiers that you will encounter will be grounded-cathode amplifiers, but the other types are found in some special applications.

The grounded-cathode amplifier is important because a high gain can be obtained from this type of circuit. This type of amplifier has a high input impedance and a high output impedance.

The cathode follower circuit always has a gain of less than one. This means that the output will be less than the input. This circuit is often used as an impedance-matching device; it has a high input impedance and a low output impedance.

The grounded-grid amplifier is often used as an rf power amplifier. It is particularly useful with triode tubes operating at very high frequencies and with beam power tubes having a high sensitivity. In conventional circuits, the screen may not offer enough isolation to prevent a beam power tube with a high sensitivity from oscillating.

SELF-TEST QUESTIONS

(ax) Where are the signal source and the load placed in a grounded-cathode amplifier?

(ay) Name two important characteristics of the grounded-cathode amplifier?

(az) What is the more common name by which the grounded-plate amplifier is known?

(ba) Where are the signal source and load placed in the cathode follower?

(bb) How does the amplitude of the output signal compare with the amplitude of the input signal in a cathode follower?

(bc) How does the phase of the output signal compare with the phase of the input signal in a cathode follower?

(bd) Name two important applications where a cathode-follower stage may be used?

(be) Where are the input signal and load placed in the grounded-grid amplifier?

(bf) How is oscillation prevented when a triode tube is used as an rf amplifier in a grounded-grid circuit?

(bg) How do the input impedances of the grounded-cathode and cathode-follower stages compare?

(bh) How do the output impedances of the grounded-cathode and cathode-follower stages compare?

LOOKING AHEAD

In later lessons many of the circuits you have studied in this lesson will be discussed in much more detail. The purpose of this lesson is to give you a look at some of the circuits in which tubes are used in order to help you better understand how tubes work. Later you will see that there are many other important things to be considered in the various stages that we have studied.

It is important for you to understand how all the various types of circuits commonly found in electronic equipment operate. You will remember that we have pointed out several times that complex electronic equipment is made up of a large number of simple circuits connected to work together. If you understand how the individual circuits work, you will be able to understand how they work together. If you understand how a piece of electronic equipment is supposed to work, you should have no difficulty locating a defect in the equipment.

Answers To Self-Test Questions

(a) A Class A amplifier is an amplifier that is biased to operate midway between zero bias and cut-off bias.

(b) A Class B amplifier is an amplifier operated with the bias approximately at cut-off.

(c) A Class C amplifier is an amplifier operated with a bias two to four times cut-off bias.

(d) Voltage amplifiers and power amplifiers.

(e) A voltage amplifier is an amplifier that is designed to take a small signal voltage and amplify it to a larger signal voltage.

(f) Voltage amplifiers are Class A amplifiers.

(g) The chief disadvantage of a Class A power amplifier is its relatively poor efficiency.

(h) The maximum theoretical efficiency that can be obtained from a Class A power amplifier is 50%. However, usually efficiencies in the order of 30% to 35% are all that is practical to obtain.

(i) A single Class B audio amplifier cannot be used because it produces only one half of an input cycle. However, two tubes can be used as a Class B power amplifier providing they are arranged so that one tube reproduces one half of the input cycle, and the other tube reproduces the other half of the input cycle.

(j) Class C power amplifiers are used to amplify radio-frequency signals.

(k) A Class AB amplifier is an amplifier operated with a bias between the value that would normally be used for a Class A amplifier and the value that would normally be used for a Class B amplifier. Sometimes Class AB amplifiers are designated as Class AB_1 or Class AB_2. A Class AB_1 amplifier does not draw any grid current and hence is very much like a Class A amplifier. A Class AB_2 amplifier does draw grid current and hence is operated closer to a Class B amplifier.

(l) Voltage amplifiers and power amplifiers.

(m) See Fig. 6.

(n) The grid-bias battery can be eliminated in a voltage amplifier by inserting a suitable resistor in the cathode circuit of the tube. Current flowing from B- through the resistor, to the cathode of the tube, then from the cathode to the plate and back to the B+ will develop a voltage drop across the cathode resistor. If the cathode resistor is of the correct size, the cathode will be sufficiently positive with respect to ground to provide the required bias. The grid will be essentially at ground potential and therefore negative with respect to the cathode. If the voltage between the cathode and ground is equal to the required grid bias, the tube grid will have the correct negative bias applied to it.

(o) Electrons accidentally striking the grid of the tube flow through the grid resistor back to ground and to the cathode of the tube. If the grid resistor is made too large, these electrons will develop an undesired voltage across this resistor. The size of the resistor is limited by the number of electrons striking the grid of the tube.

(p) The capacitor is used to hold the voltage across the cathode-bias resistor constant. The signal applied to the grid of the tube causes an ac current, which is superimposed on the dc current flowing through the tube, to flow in the cathode circuit. This ac current in effect flows through the bypass capacitor so that the voltage across the bias resistor does not vary.

(q) The output transformer is a step-down transformer. The transformer is primarily an impedance-matching device; it matches the low-impedance speaker to the higher impedance of the tube.

(r) The complete statement is as follows: a power amplifier using one tube such as shown in Fig. 8 is called a single-ended stage, whereas one using two tubes such as shown in Fig. 9 is called a double-ended stage.

(s) A voltage amplifier. The radio frequency amplifier used in a radio or television receiver is used to build up or amplify the voltage of a weak signal picked up by the antenna.

(t) C3 is a screen bypass capacitor. It is used to place the screen at signal ground potential so that the screen will provide maximum shielding between the plate and grid of the tube.

(u) A Class C power amplifier has the best efficiency; a Class A amplifier has the poorest efficiency.

(v) Both detectors and rectifiers work on the principle of allowing current to flow through them in only one direction.

(w) Sixty pulses per second. The rectifier will conduct once each cycle and therefore on a 60-cycle power line you will get 60 pulses per second.

(x) 120 pulses per second. A full-wave rectifier conducts on each half cycle. Since there are two half cycles in each cycle, on a 60-cycle power line you will get 120 pulses.

(y) The increased number of pulses per second from a full-wave rectifier makes it easier to filter the pulsating dc to pure dc. Thus smaller filter chokes and filter capacitors may be used with a full-wave rectifier rather than with a half-wave rectifier.

(z) See Fig. 14.

(aa) The variation in the strength of the signal being received causes the amplitude of the pulses flowing through a diode detector to vary. This variation in signal received is the modulation or intelligence signal that is placed on the rf carrier.

(ab) In the grid circuit. In a grid-leak detector the grid and cathode act like a diode tube. The grid acts like a plate, and when the input signal swings the grid positive, current flows from the cathode to the grid of the tube. When the input signal swings the grid negative, no current flows from the cathode to the grid.

(ac) We can compare the grid-leak detector to a diode detector followed by a triode amplifier stage.

(ad) Part of the signal from the output of the oscillator is fed back to the input circuit. This signal is called the feedback signal or simply feedback.

(ae) See Fig. 17.

(af) The grid bias is developed across the grid resistor, R1. This bias is self-regulating; in other words, if the output of the stage tends to increase, the bias will increase to hold the output down. If the output tends to decrease, the bias will decrease to permit the output signal to increase.

(ag) C3 and L1.

(ah) Feedback is controlled by the feedback capacitors C3 and C4. These capacitors form a voltage divider network to control the amount of signal fed from the output back to the grid-cathode, which forms the input circuit.

(ai) L1, C5, C3 and C4 control the oscillator frequency.

(aj) A sine-wave signal.

(ak) The output signal from a multivibrator is essentially a square wave.

(al) C1 - R2 and C2 - R3 control the multivibrator frequency.

(am) The multivibrator shown in Fig. 19 is called a plate-coupled multivibrator. It is given this name because the energy necessary for oscillation is fed between the tubes from the plate of each tube to the grid of the other tube.

(an) The mixer stage. This stage is sometimes referred to as the mixer-oscillator stage because the two functions of mixing and oscillation are performed in a single tube in a five-tube superheterodyne receiver.

(ao) The oscillator frequency is higher than the frequency of the incoming signal.

(ap) 1956kc. The i-f frequency in a receiver is equal to the difference between the local oscillator frequency and the frequency of the incoming signal. If the oscillator operates higher than the incoming signal, then the oscillator frequency must be equal to the frequency of the incoming signal plus the frequency at which the i-f amplifier operates. Therefore, in this case the oscillator frequency must be 1500 + 456 = 1956 kc.

(aq) The second grid acts as the plate of the triode section of the tube which in turn is the oscillator section.

(ar) The primary winding along with the capacitor connected across it form a parallel-resonant circuit because the signal is fed to the coil and capacitor in parallel. The secondary circuit consisting of the coil and capacitor form a series-resonant circuit because the signal is induced in series with the turns of the coil.

(as) A remote cut-off tube is a tube with a grid specially constructed so that it takes a rather large negative bias to cut off the flow of plate current through the tube. This type of tube is normally used in i-f amplifier stages through which an automatic volume control voltage is fed.

(at) The audio signal voltage is developed by the second detector across a 220 pf capacitor C8.

(au) Bias for the first audio stage is developed across the 6.8 megohm resistor, R8. As you will remember, a few of the electrons leaving the cathode of the tube and travelling toward the plate will actually strike the grid of the tube. These few electrons flowing through R8, which has a high resistance, will develop a small voltage across this resistor having such a polarity that the grid end is negative. This voltage biases the stage.

(av) The power amplifier stage is a Class A power amplifier.

(aw) The chances are good that one of the tubes may have a burned-out heater. Since the tubes are connected in series, if any tube has a burned-out heater this will open the circuit and none of the tubes will light. However if all the tubes are good, there is a possibility that the on-off switch, the line cord, or the line-cord plug may be defective. In addition, the socket into which the receiver is plugged may be at fault. However, in most receivers of this type, when all the tubes fail to light, the heater of one of the tubes is burned out.

(ax) The signal source is placed between grid and cathode, and the load is placed in the plate circuit of the tube.

(ay) The output signal will be greater than the input signal, and the output signal will be 180° out of phase with the input signal.

(az) A cathode follower.

(ba) The signal source is placed between grid and ground, and the load is placed between the cathode and ground.

(bb) The output signal is always lower in amplitude than the input signal. We say that the gain of a cathode follower is less than one - in other words, there is a loss in signal amplitude in this stage.

(bc) In a cathode follower the output signal will be in phase with input signal.

(bd) Where it is important not to change the phase of the signal, and in impedance-matching applications.

(be) The input signal is placed between the cathode and ground, and the load is placed in the plate circuit.

(bf) In a grounded-grid amplifier the grid is grounded and acts to shield the output circuit from the input circuit and by so doing prevents feedback which could cause oscillation.

(bg) Input impedances of both types of stages are high.

(bh) The output impedance of a grounded-cathode stage is comparatively high, but the output impedance of a cathode-follower stage is low.

Lesson Questions

Be sure to number your Answer Sheet B111.

Place your Student Number on every Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time, or you may run out of lessons before new ones can reach you.

1. Which element of a tube is operated at signal ground potential when the tube is used as a cathode follower?

2. Which class of amplifier is operated with a bias several times cut-off bias?

3. What will normally happen to the average plate current of a properly biased Class A amplifier when a symmetrical ac signal is applied to the amplifier?

4. What is the purpose of R2 in Fig. 6?

5. In the circuit shown in Fig. 11, what current develops bias for the stage?

6. Which type of rectifier, a half-wave or a full-wave, requires more filtering to get pure dc?

7. In which circuit does detection occur in the grid-leak detector?

8. On what basic principle do oscillators work?

9. What does avc found in modern receivers do?

10. What type of amplifier can be used to match a high impedance to a low impedance?

TOMORROW NEVER COMES

The fellow who coined the phrase, "Don't put off till tomorrow what you can do today," was one of the world's wisest men. As a sure-fire formula for success, this certainly hits the nail on the head.

Perhaps NRI men wonder why I repeat this warning so often. It is because I am convinced that of all the reasons for failure, this habit of "putting off" is the greatest. We can always find a good excuse for "putting off." We can easily convince ourselves that we are too tired (or lazy?), or that we don't feel well, or that it's too hot, or that we have too much to do. The reason we are "putting off" is not important; the fact that we are "putting off" is.

The best -- in fact, the only -- way to overcome this temptation is never to succumb to it. The first time you find yourself saying, "I'll skip studying tonight and do twice as much tomorrow," is the time to study twice as hard as usual. Soon you will no longer have to fight temptation; it will no longer exist. It won't occur to you to say, "I'll do it tomorrow." Instead, you will automatically say, "I'll do it now."

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HOW TRANSISTORS WORK

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STUDY SCHEDULE

By dividing your study into the steps given below, you can get the most out of this part of your NRI Course in the shortest possible time. Check off each step when you finish it.

☐ 1. **Introduction** .... **Pages 1 - 2**
You learn some of the advantages and disadvantages of transistors compared to vacuum tubes.

☐ 2. **Semiconductor Fundamentals** .... **Pages 3 - 13**
You learn about conductors, insulators and semiconductors. You study important characteristics of germanium and silicon and how they are "doped" for use in transistors.

☐ 3. **Current Flow in Semiconductors** .... **Pages 14 - 18**
You study current flow in N-type and P-type semiconductor material.

☐ 4. **Semiconductor Diodes** .... **Pages 18 - 29**
You learn about current flow in diodes with forward bias and reverse bias. You study several important types of diodes.

☐ 5. **Semiconductor Triodes** .... **Pages 30 - 39**
In this section you study PNP and NPN transistors and how they are biased.

☐ 6. **Semiconductor Types** .... **Pages 39 - 52**
In this section you learn about a number of different types of transistors. You also study field-effect and unijunction transistors.

☐ 7. **Answers to Self-Test Questions** .... **Pages 52 - 56**

☐ 8. **Answer the Lesson Questions.**

☐ 9. **Start Studying the Next Lesson.**

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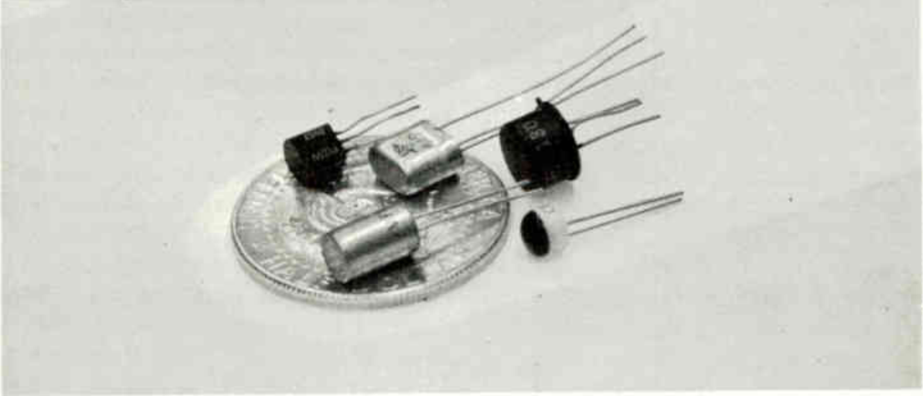
HOW TRANSISTORS WORK



In the preceding lessons you studied tubes, and you saw how they are used in different circuits. In this lesson you will study semiconductor devices - these devices have already replaced tubes in many important applications and are rapidly moving into new areas that were once dominated entirely by tubes.

An example of the importance of semiconductor devices can be seen in entertainment-type equipment. Just a few years ago all the rectifiers used in this equipment were vacuum tubes. Today, however, the vacuum tube is no longer used for this purpose; rectifiers in the modern entertainment-type equipment are all semiconductor devices.

Semiconductor devices used as rectifiers have two elements and are called diodes just as two-element vacuum tubes are called diodes. Semiconductors used to amplify signals usually have three or more elements and are called transistors. There are a large number of different types of transistors available today, but for the most part these transistors can be classified into two types, the NPN transistor and the PNP transistor. If you understand how these two transistor types work, you should have little difficulty understanding how all others work and any new transistors that might be introduced in the future. You will run into many different types of transistors identified by different names, but these names usually refer to the method used in manufacturing the transistor rather than the manner in which it operates.

There are some similarities between tubes and semiconductors. A two-element vacuum tube can be used to change an alternating current to a direct current; a two-element semiconductor can be used for the same purpose. A triode vacuum tube can be used to amplify a signal; a transistor can be used for the same purpose. However, this is where the similarity ends. Most tubes are vacuum devices; in other words, all the air and gas have been evacuated from inside the tube. On the other hand, a semiconductor is a solid device and there is no space between the elements in it. We have a current flow through a vacuum in a tube, but we have a current flow through a solid in a semiconductor.

The importance of semiconductors cannot be overemphasized. They have completely supplanted the vacuum tube in portable radio receivers and in automobile receivers. Almost all high fidelity and stereo equipment manufactured today uses semiconductors exclusively - the only tube-operated equipment of this type you are likely to encounter is equipment that is several years old. Semiconductors are finding their way into television receivers and it is probably just a matter of time before they completely replace the vacuum tube.

Semiconductors have several advantages over the vacuum tube. Perhaps one of the most important advantages is that they do not require any heater or filament power. Not only is this a power saving in the operation of the equipment, but it also removes considerable heat from the equipment. Heat is probably the thing that causes the most damage to parts in electronic equipment. Thus with the removal of the heater or filament power from the equipment, other components such as capacitors, etc. will last longer.

Semiconductors are very rugged. They are solid devices and hence not subject to breakage from mechanical shock as tubes are. An important advantage of transistors is that they will operate on a comparatively low voltage, and this usually results in some reduction of the power required in the equipment.

Although semiconductors have many advantages over vacuum tubes, they do have some disadvantages. One disadvantage is that it is usually not possible to get as high a gain in an amplifier stage using a transistor as it is in a similar stage using a tube. Therefore to get the equivalent gain, more transistor stages are required than vacuum-tube stages. Another disadvantage of the transistor is that its characteristics are not as constant as those of a vacuum tube. In other words, you are more likely to run into difficulty replacing a transistor than you are in replacing a tube because the replacement transistor's characteristics might be considerably different from the characteristics of the original transistor. Another disadvantage of both diode semiconductors and transistors is that their characteristics can vary appreciably with changes in temperature. As a matter of fact, some semiconductor devices are easily destroyed by too much heat.

In spite of the fact that semiconductor devices have some disadvantages when compared to vacuum tubes, their advantages more than outweigh the disadvantages and their importance in the field of electronics is continually growing. Therefore it is important that the technician have a good understanding of semiconductor fundamentals, how they are used, and how they operate. Before going ahead to see how semiconductors are used as rectifiers and amplifiers, we need to know more about certain types of atoms, in order to understand how these devices work.

Semiconductor Fundamentals

You have already learned that certain materials will conduct electricity readily and that some materials will hardly pass any electric current at all. The materials that will conduct current readily are called conductors and those that will not conduct current are called insulators. Midway between the two types of materials is a group of materials called semiconductors. These materials are not good conductors, nor are they particularly good insulators. Two examples of semiconductor materials are germanium and silicon. These are the materials that we will be mostly concerned with in this section. Both diode semiconductors and transistors are made from germanium and silicon. A new material that shows promise for use in semiconductors is gallium arsenide. It's likely that this material will be used in semiconductors in the future. Before going ahead with our detailed study of semiconductor materials, let us review a few important facts about conductors and insulators.

CONDUCTORS AND INSULATORS

You will remember that all materials are made up of atoms. An atom is the smallest particle of a material that retains the characteristics of the material.

In the center of the atom is the nucleus. This nucleus contains a positive charge. The number of positive charges on the nucleus distinguishes one material from another. In other words, the nucleus of a copper atom does not have the same number of positive charges as the nucleus of an iron atom.

Each atom normally has enough electrons, which have a negative charge, to exactly neutralize the positive charge on the nucleus. Thus, the hydrogen atom which has a nucleus with one positive charge will have one electron, and the helium atom which has a positive charge of two in the nucleus will have two electrons. Another atom that has a nucleus with 30 positive charges will have 30 electrons to exactly neutralize the positive charge on the nucleus.

The electrons in an atom arrange themselves in shells around the nucleus. The total number of electrons will normally be just enough to neutralize the charge on the nucleus. However, there is a maximum number of electrons that can be forced into each shell. In the first shell around the nucleus, the maximum number of electrons is 2. In the second shell, the maximum number of electrons is 8, and in the next shell the maximum number of electrons is 18. A shell can have less than the maximum number of electrons, but not more than the maximum number.

Conductors.

An example of an atom in a conductor is shown in Fig. 1. We have drawn the shells in the form of rings, but remember that this atom actually has three dimensions, not two. Notice that in this atom there are two electrons in the first shell,

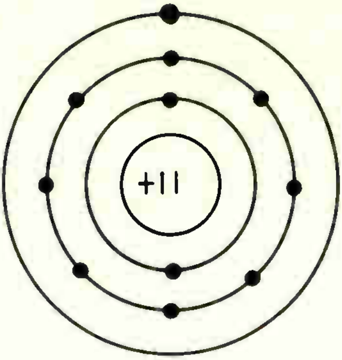


Fig. 1. An atom of a conductor.

8 electrons in the next shell and only one electron in the third shell. The outer shell is called a valence shell. The single electron in the third shell, which is called the valence electron, is not very closely bound to the nucleus; it can easily be removed from the atom. Thus a material of this type has a large number of electrons that can easily be removed from their atoms. When these electrons are forced to move in one direction we have a current flow. Thus a material that has only one or two electrons in an outer shell that could have many more, is a conductor, because the one or two electrons in the outer shell are not closely bound to the nucleus.

Insulators.

An atom of an insulator is shown in Fig. 2. Notice that in this atom there are two electrons in the first shell, and 8 electrons in the second shell. Both the shells are completely filled and will be closely bound to the nucleus. This means that it is very difficult to get one of these electrons out of an atom and therefore this material is an insulator or nonconductor.

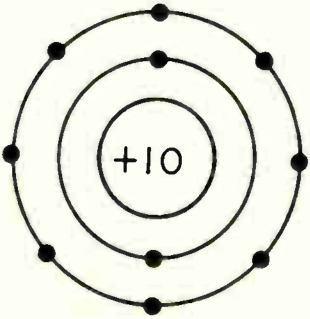


Fig. 2. An atom of an insulator.

Remember the important difference between conductors and insulators. A conductor is a material that has one or two electrons in the outer shell that are not closely bound to the nucleus, whereas an insulator is a material in which the outer shell of each atom is filled or almost filled so that the electrons are closely bound to the atom and cannot be easily removed. Because these electrons cannot be removed from the atom, this type of material normally will not conduct current, and hence is called an insulator.

SEMICONDUCTOR MATERIAL

A material that is classified as a semiconductor has electrical characteristics midway between those of a conductor and those of an insulator. The electrons in a semiconductor can be removed from their atoms when some type of external energy, such as voltage, heat, or light is applied to the material. Then the material acts like a conductor.

The most important semiconductor materials used for transistors are germanium and silicon. The first low-cost transistors were germanium transistors, but recent developments have lowered the cost of silicon transistors so that most of the new transistor types being introduced are silicon. Both germanium and silicon are very abundant elements, but neither is found in the pure state, and it is quite difficult to process them to the high state of purity required for use in transistors. The first transistors were made of germanium because techniques for getting pure germanium were developed first. However, now it is possible to refine silicon to the high degree of purity required, at a reasonable cost, and since silicon has several advantages over germanium for use in semiconductor devices it has in many ways replaced germanium.

In general, there is not too much difference between the operation of semiconductor devices made from germanium and those made from silicon. We will cover the important points of these devices made from both materials since you will run into semiconductor devices of both types.

The Germanium Atom.

The arrangement of electrons about the nucleus in a germanium atom is shown in Fig. 3A. The nucleus of the germanium atom has a positive charge of 32. Thus as you might expect, there will be 32 electrons revolving in the shells about the nucleus. There are two electrons in the first shell, eight in the second, eighteen in the third and four in the fourth shell. Thus, the first, second and third shells are filled, but there are only four electrons in the outer shell. However, these four electrons, which are called the valence electrons, are bound to the nucleus much more so than the one or two electrons found in the outer shell of a conductor.

The important electrons in the germanium atom, insofar as its use in semiconductors is concerned, are the four electrons in the outer shell because the shell is not filled. The other electrons are bound so closely to the nucleus that they cannot easily be removed. Therefore, germanium is often represented as shown in Fig. 3B.

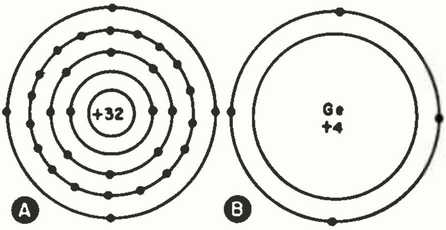


Fig. 3. (A) is the germanium atom with a charge of 32. (B) shows the simplified symbol.

The Silicon Atom.

The arrangement of electrons about the nucleus in a silicon atom is shown in Fig. 4A. The nucleus of the silicon atom has a positive charge of 14. Therefore, there will be fourteen electrons revolving about the nucleus. There are two electrons in the first ring, eight in the second and four in the third. Thus the first and second rings are filled, but there are only four electrons in the outer shell. These four

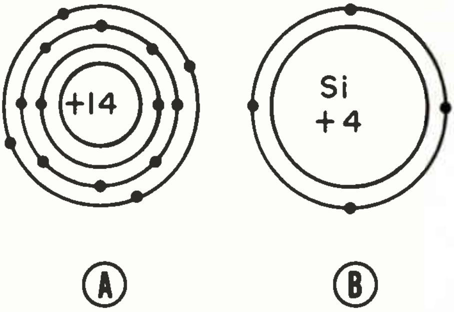


Fig. 4. (A) shows the silicon atom with a charge of 14. (B) shows the outer shell with four electrons.

electrons are the valence electrons like the four in the germanium atom and are bound fairly closely to the nucleus. As in the case of the germanium atom, the four electrons in the outer ring are the ones that are of importance in the use of silicon in semiconductors.

Notice the similarity between the silicon and germanium atoms. In both atoms, the outer shell or ring has four electrons, and all the other shells are filled.

The tendency of some materials like silicon and germanium, that do not have the outer shell completely filled with electrons, is to get additional electrons to fill up the outer shell. In pure germanium and silicon, the electrons in the outer shell of one atom are bound as closely to that atom as the four electrons in the outer shell of another atom. Therefore one atom cannot pull electrons away from another atom. Instead, two nearby atoms will share one outer electron from each atom. In other words, two atoms of germanium may share electrons as shown in Fig. 5A; and two atoms of silicon may share electrons as shown in Fig. 5B. By sharing electrons in this way, each atom will partly fill its outer shell. This pair of shared electrons, one from each of two atoms, is called "a covalent bond".

In order to try to fill its outer ring with electrons, a single germanium atom or a single silicon atom will establish covalent bonds with four other atoms. This arrangement of atoms in a piece of germanium is shown in Fig. 6A. A similar arrangement of atoms in a piece of silicon is shown in Fig. 6B. These pieces of silicon and germanium are called crystals and the way in which they are arranged is called a lattice structure. Each atom shares each of its four valence electrons with one valence electron of another atom to form these bonds.

INTRINSIC CONDUCTION

Even at comparatively low temperatures, there is heat energy in all materials. This energy is sufficient to cause a few of the electrons to move out of their proper place in the lattice structure of either the germanium crystal or the silicon crystal and become free electrons. These free electrons are available for conduction of electric current. The number of free electrons available is much higher in germanium than it is in silicon.

When one of these electrons moves out of its position in the lattice structure, it leaves an empty space in the crystal lattice. This empty space is called a hole. An electron from a

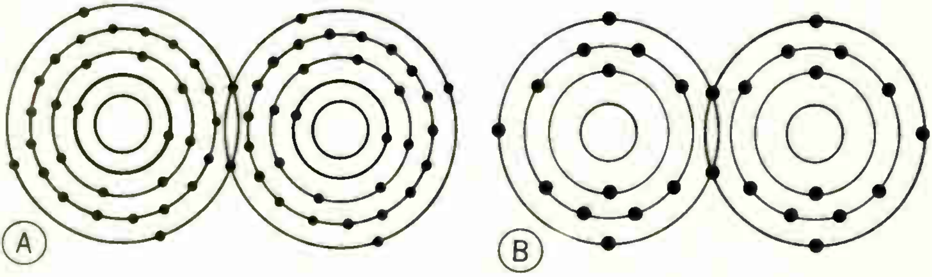


Fig. 5. The sharing of two electrons by two germanium atoms is shown at A; by two silicon atoms at B.

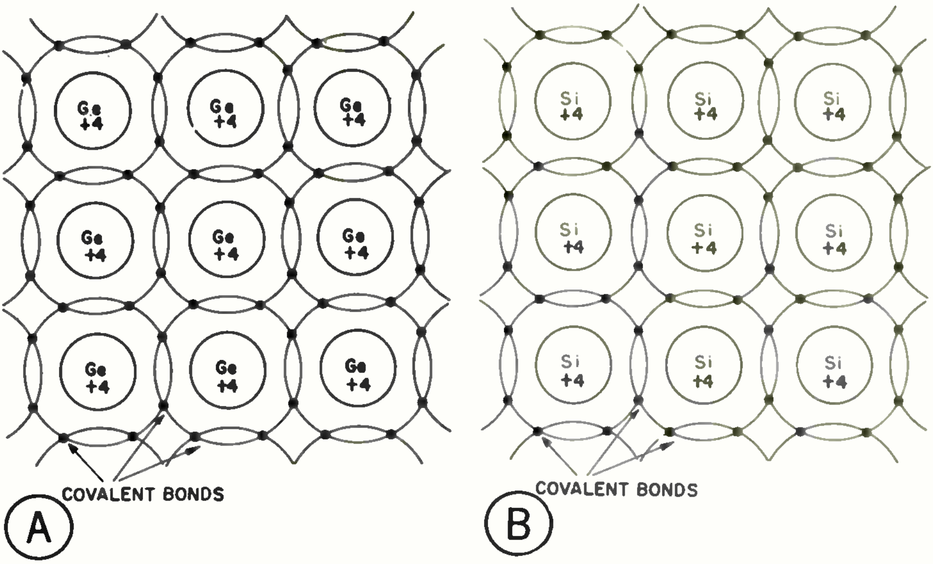


Fig. 6. The lattice structure of germanium is shown at A; of silicon at B.

nearby atom can move into this hole thus creating a new hole at the place it left. Another electron may move out of still another atom to fill this new hole, leaving behind it a hole. This movement of an electron to fill a hole thus creating a new hole in the place it left makes it look as if holes themselves move. Furthermore, since the hole represents a missing electron, it has a positive charge.

In a piece of germanium or silicon, the electrons are in a constant state of motion about their atoms. If in its movement an electron comes closer to a hole than to its own atomic nucleus, it will be strongly attracted to the hole and will leave its atom. When there is no voltage applied across the crystal, the movement of a hole or an electron is a random movement. Holes and electrons may move in any direction.

If heat or some other form of external energy is applied to the crystal, the resistance of the material is reduced. This happens because more electrons are freed by the energy applied to the crystal. In addition, the speed of the random movement is increased.

The movement of an electron out of an atom forms a hole in the atom. Thus, whenever an electron is freed from an atom a hole is formed. This free electron and the hole it forms are called a "hole-electron pair". The formation of hole-electron pairs is a continuous process. Also the filling of holes by electrons is a continuous process. In other words, the process of an electron leaving its atom and forming a hole, and another electron moving in to fill the hole and in so doing creating a new hole, is a continuous process. The conduction of electricity in pure germanium or pure silicon crystals due to the formation of hole-electron pairs is called the intrinsic conduction.

The conductivity of a germanium crystal or a silicon crystal, which is the ability of the material to conduct an electric current, depends on the average length of time an electron is free and on the number of free electrons. We mentioned previously that there are more electrons free if external energy, such as heat, is applied to the material. Therefore the conductivity rises as the temperature of the material is increased.

This type of conduction is much higher in germanium than it is in silicon. As an example, if we had a germanium crystal exactly one centimeter on each side and measured the resistance across two parallel surfaces, we would find the resistance to be approximately 60 ohms. The resistance of an equivalent piece of silicon would be approximately 60,000 ohms. Thus intrinsic conduction is much higher in germanium than it is in silicon.

Intrinsic conduction in transistors is undesirable. It is kept as low as possible by holding the operating temperature of the material down. Transistors are also shielded from light because light is a form of energy and light striking the crystal will increase the intrinsic conduction. Since silicon has a much lower intrinsic conduction than germanium, semiconductors made from silicon are less affected by heat than are semiconductors made from germanium. This is one of the chief advantages of silicon over germanium as a semiconductor material.

In their pure forms, neither germanium nor silicon are useful in semiconductor devices. In fact, in spite of intrinsic conduction, neither material is a good conductor at room temperature; they are both fairly good insulators. To use these materials in semiconductors, controlled amounts of other selected elements called impurities are added to the crystals to alter their characteristics. By adding these materials we can produce two types of silicon and two types of germanium. They are called N-type and P-type. Now, let us study the characteristics of these two types of materials.

N-TYPE MATERIAL

N-type silicon or germanium can be produced by adding as an impurity an element that has five electrons in its outer ring. An example of this type of material is arsenic. Arsenic has a positive charge of 33 on the nucleus and has 33 electrons in the shells surrounding the nucleus. There are two electrons in the first shell, eight in the second, eighteen in the third and five in the fourth or outer shell. In other words, arsenic is just like germanium except that the nucleus has one more positive charge and there is one additional electron in the outer shell.

If a small amount of arsenic is added to the germanium, the arsenic atoms will form covalent bonds with the germanium atoms as shown in Fig. 7. However, to form the covalent bonds with its neighboring germanium atoms, the arsenic atom needs only four of the electrons in its outer shell. Therefore there will be one electron left over when the arsenic atom forms covalent bonds with the four neighboring germanium atoms. This electron is free to move about within the crystal in exactly the same manner as a single valence electron in a good metal conductor. The addition of arsenic, which produces these free electrons, greatly reduces the resistance of the material.

When a small amount of arsenic

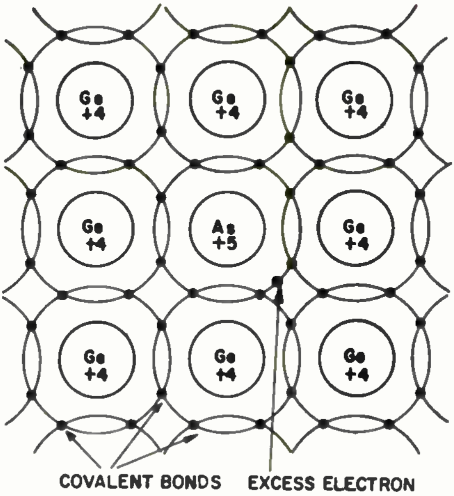


Fig. 7. Germanium with arsenic added.

is added to a silicon crystal exactly the same thing happens. The arsenic atom forms covalent bonds with the silicon atoms. As in the case of the germanium atom, only four of the electrons in the outer shell of the arsenic atom are used in forming these covalent bonds so there will be one electron left over.

When germanium or silicon have had an impurity added to them we say they have been doped. When semiconductor material has been doped with a material such as arsenic that results in there being excess electrons, we call it an N-type material. The N refers to the negative carriers, which are the free electrons. Arsenic is called a donor impurity because it donates an easily freed electron.

In addition to arsenic, other materials have been used as donors. Phosphorus, which has a total of fifteen electrons, can be used. The phosphorus atom has two electrons in the first shell, eight in the second and five in the third. Four of the electrons in the valence shell or ring will form covalent bonds with germanium or silicon atoms leaving a fifth electron free. Antimony, which has 51 electrons, also has been used as a donor. Antimony has two electrons in the first shell, eight in the second, eighteen in the third, eighteen in the fourth and five in the fifth or valence shell.

P-TYPE MATERIAL

If instead of adding a material with five electrons in its valence shell, we add a material with only three electrons in the valence shell, we have a situation where the impurity added to the silicon or germanium has one less electron than it needs to establish covalent bonds with four neighboring atoms. Thus, in one covalent bond there will be only one electron instead of two. This will leave a hole in that covalent bond.

A material that is frequently used for this purpose is indium. Indium has 49 electrons, two in the first shell, eight in the second, eighteen in the third, eighteen in the fourth and three in the fifth or valence shell.

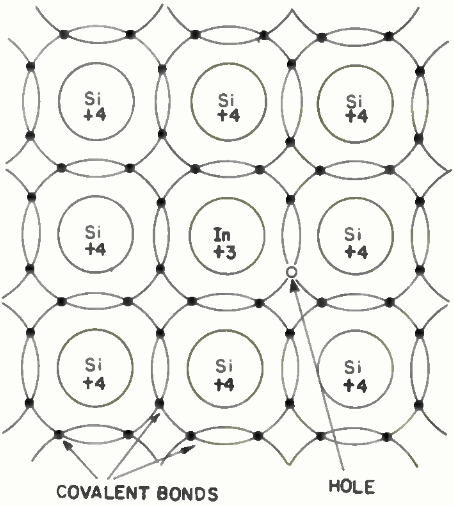


Fig. 8. Silicon with indium added.

The manner in which indium forms covalent bonds with neighboring silicon atoms is shown in Fig. 8. It forms covalent bonds with germanium atoms in the same way.

We mentioned previously that even at comparatively cold temperatures there is some heat energy within the crystal and thus there will be a few free electrons moving about the crystal. These free electrons are strongly attracted to the holes in the covalent bond produced where an indium atom has replaced a silicon or a germanium atom. Thus an electron will move into a hole in the covalent bond producing a new hole in another atom and giving the effect that the hole is moving as shown in Fig. 9.

Since a hole in the crystal actually represents a shortage of an electron, it is an area with a positive charge. Therefore when a semiconductor material has been doped with a material such as indium that produces holes in the lattice structure, we call it a P-type material.

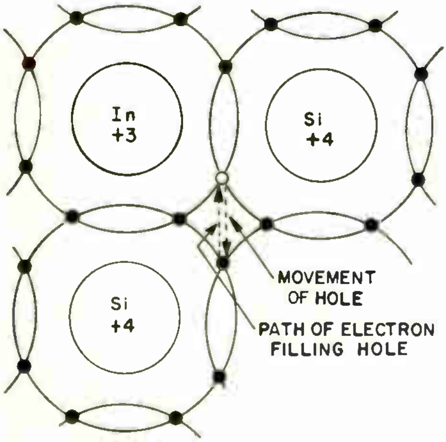


Fig. 9. When an electron fills a hole, another hole will apparently move to where the electron was.

P stands for positive; since holes represent a shortage of an electron we say they act as positive carriers. The indium is called an accepter impurity because its atoms leave holes in the crystal structure that are free to accept electrons. In addition to indium, boron and aluminum are also used as accepter impurities. Boron has 5 electrons, two in the first shell and three in the second which is the valence shell. Aluminum has 13 electrons, two in the first shell, eight in the second and three in the third or valence shell.

CHARGES IN N-TYPE AND P-TYPE MATERIAL

When a donor material such as arsenic is added to germanium or silicon, the fifth electron in the valence ring of the arsenic atom does not become part of a covalent bond. This extra electron may move away from the arsenic atom to one of the nearby germanium or silicon atoms.

The arsenic atom has a charge of +33 on the nucleus and normally has 33 electrons to neutralize this charge. When the electron moves away from the atom there will be only 32 electrons to neutralize the charge on the nucleus, and as a result there will be a small region of positive charge around the arsenic atom. Similarly, the excess electron that has moved into a nearby germanium or silicon atom will provide an excess electron in the atom. In the case of the germanium atom there will be a total of 33 electrons around a nucleus requiring only 32 electrons to completely neutralize it, and in the case of the silicon atom there will be 15 electrons around the nucleus requiring only 14 electrons to neutralize it. This means that the atom will have an extra electron so that there will be a region of negative charge around this atom.

It is important to notice that although there is a region of positive charge around the arsenic atom after the electron has moved away, and a region of negative charge around the germanium or silicon atom taking up the extra electron, the total charge on the crystal remains the same. In other words, a given crystal will have a net charge of zero. This means that there will be exactly enough electrons to neutralize the positive charges on the nuclei on the various atoms. But because some of the electrons may move about in the crystal, there will be regions in the crystal where there are negative charges and other regions where there are positive charges, even though the net charge on the crystal is zero.

In a P-type material to which material such as indium has been added we will have a similar situation. You will remember that the indium atom has only three electrons in its valence ring. These are all that were needed to neutralize the positive charge on the nucleus. However, with only three electrons in the valence ring, there is a hole in one of the covalent bonds formed between the indium atom and the four adjacent germanium or silicon atoms. If an electron moves in to fill this hole, then there is one more electron in the indium atom than is needed to neutralize the charge on the nucleus. Thus there will be a region of negative charge around the indium atom. Similarly, if one of the germanium or silicon atoms has given up an electron to fill the hole in the covalent bond, then the atom which has given up the electron will be short an electron so that there will be a region of positive charge around this atom. Again, while this giving up of an electron by a germanium atom and the acceptance of an electron by the indium atom ionizes or charges both atoms involved, the net charge on the crystal is still zero. We simply have one atom that is short an electron and another atom that has one too many. The crystal itself does not take on any charge.

These ionized atoms produced in both the N-type and the P-type germanium and the N-type and the P-type silicon are not concentrated in any one part of the crystal, but instead are spread uniformly about the crystal. If any region within the crystal were to have a very large number of positively charged atoms, these atoms would attract free electrons from other parts of the crystal to neutralize part of the charged atom, so that the charge would be spread uniformly about the crystal. Similarly, if a large number of atoms within a small region have had an excess of electrons, these electrons would repel each other and spread throughout the crystal.

Both holes and electrons are involved in conduction at all times. Holes are called positive carriers and electrons negative carriers. The one present in greatest quantity is called the majority carrier; the other is the minority carrier. In an N-type material, electrons are the majority carriers and holes are the minority carriers, whereas in a P-type material, holes are the majority carriers and electrons the minority carriers.

SUMMARY

This is a very important section of this lesson. You have covered many of the fundamentals of semiconductors on which we will build the remainder of the lesson. It is important that you understand the basic theory of semiconductors in order to be able to understand how semiconductor diodes and transistors work. We will summarize the important points that were covered in the preceding section.

If any of these points are not clear, you should go back and study the lesson again until they are clear. If you understand the first section of the lesson, you should be able to understand the material following without too much difficulty. However, if you do not understand what has been covered previously, you will have difficulty understanding what is to follow.

Pure semiconductor material such as germanium or silicon is a very poor conductor. In fact, it is an insulator if it is protected from all outside sources of energy. However, even at room temperature there is enough heat present in germanium and silicon to produce some electron and hole movement. The movement is much greater in germanium than it is in silicon.

An electron movement out of a covalent bond in a germanium or silicon atom leaves a hole in that bond. The hole will attract an electron from a nearby atom, producing a hole in that atom. Thus, both the hole and the electron appear to move. The holes are positive carriers and the electrons negative carriers of electricity. This formation of hole-electron pairs is undesirable in transistors and steps are taken to keep it as low as possible. The formation of hole-electron pairs increases as the temperature increases and is a much more serious problem in germanium-type semiconductor material than in silicon-type semiconductor material.

Semiconductor materials can be doped by adding small amounts of impurities. If a material with five electrons in the valence ring is added, the material is called a donor-type impurity. This type of material has one electron left over after it forms covalent bonds with four neighboring germanium or silicon atoms. Thus there will be an excess of electrons. We then refer to this kind of material as an N-type material.

If the germanium or silicon is doped with an impurity, called an accepter impurity, having three electrons in the valence shell, the impurity forms covalent bonds with the four neighboring germanium or silicon atoms. However, there will be a hole in one of the covalent bonds because the impurity has only three electrons available to form covalent bonds with four neighboring germanium and silicon atoms. This type of germanium or silicon is called P-type because there will be holes in the material, and these holes act as positive carriers.

Another point to remember is that when an electron is freed or when a hole captures an electron, the atoms involved become charged, or ionized. Thus throughout both N-type and P-type germanium or N-type and P-type silicon we have small regions of charge. However, the net charge on the crystal is zero and the charged regions are evenly distributed throughout the material.

SELF-TEST QUESTIONS

(a) How many electrons are there in a valence shell or ring in a silicon atom?

(b) What are the two types of material most widely used in semiconductor devices?

(c) What is meant by a covalent bond?

(d) How many covalent bonds will a single germanium or silicon atom establish?

(e) What is intrinsic conduction?

(f) Is intrinsic conduction desirable?

(g) In which type of conductor material, germanium or silicon, is intrinsic conduction the greatest?

(h) What is the greatest cause of an increase in intrinsic conduction in germanium?

(i) Which semiconductor material, silicon or germanium, has greater resistance?

(j) What is an N-type material?

(k) What is a donor material?

(l) Name two materials used as donors.

(m) What is P-type material?

(n) What is an accepter impurity?

(o) Name three types of accepter material.

(p) In N-type material what is the majority carrier?

(q) What are the majority carriers in the P-type material?

(r) When a donor impurity such as arsenic loses an electron in a semiconductor material, what happens to the arsenic and to a nearby atom that gains the electron insofar as their relative charge is concerned?

(s) Although there are small areas that have positive and negative charges in a doped semiconductor, what is the overall charge on the crystal?

Current Flow in Semiconductors

In order to understand how transistors operate, there are several new ideas that you must master. First, you must understand how current flows through both N-type and P-type semiconductor materials. Current flow through an N-type material is not too different from current flow through metals, which you have already studied. However, there is quite a difference in the way current flows through a P-type material.

When a P-type material is placed next to an N-type material, we have what is called a junction. The action that occurs at the point of contact between these two different types of materials is extremely important. It is this action that makes the transistor possible.

In this section of the lesson we will study how current flows through N-type and P-type materials. We need to understand current flow through both types of germanium or silicon to be able to understand how a junction works. In a later section we will see how a junction works. Later, we will see what happens in a transistor, which has two junctions.

This section is extremely important, and you should be sure that you understand it completely. Once you understand this material, it will be a simple step to see how transistors can be used to amplify signals.

DIFFUSION

As we have mentioned, adding impurities to pure germanium or silicon adds free electrons or holes. You might at first think that when there is no voltage applied there would be no motion of the free holes and electrons. However, this is not true--as you learned when we discussed intrinsic conduction, there is a certain amount of energy present in the crystal. This energy might be due to the temperature of the crystal, because as we pointed out before, even at room temperature the crystal does have heat energy. Motion of the free holes or electrons due to energy of this type is at random; in other words there is no net movement in any one direction. Holes move one atom at a time, and any hole may move from its starting location to any of the surrounding atoms. This means that a hole may start off in one direction as it moves from one atom to another, and then may move in almost the opposite direction as it moves to still a third atom. Similarly, electron movement is in a random direction; a given electron may move in first one direction and then in another.

When electrons and holes are in motion, the different carriers are moving in different directions. Remember that when there is a hole in one atom, and an electron moves from another atom to fill that hole, a new hole appears in the second atom. In other words, the electron has moved from the second atom to the first, whereas the hole has moved in the opposite direction from the first atom over to the second atom that gave up the electron. The result is that the effective current flow of any one carrier is cancelled by the movement of the other carrier and the resulting current flow in any direction is zero.

This random motion of carriers is called diffusion. It goes on at all times in a crystal whether there is a voltage applied to the crystal or not. Every effort is made in the design of transistors to keep this diffusion as low as possible.

DRIFT

Another type of carrier movement in semiconductors is known as "drift". This is the type of movement that is obtained when a voltage is applied across the crystal. Since the manner in which current flows through N-type and P-type material is different, let's consider them separately.

N-Type Material.

In Fig. 10 we have shown an N-type crystal with a voltage applied to it. The voltage difference supplied by the battery provides a force which makes it easier for the electrons to move in one direction than in the other. In an N-type material, the electrons will be attracted by the positive terminal of the battery. Because in the N-type material the electrons greatly outnumber the holes, they will carry the current.

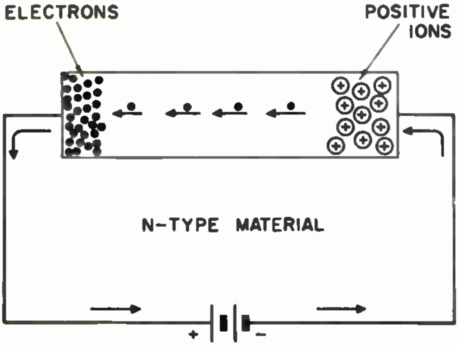


Fig. 10. N-type crystal with voltage applied to it.

When the electrons are attracted by the voltage applied to the positive terminal, they will move towards the positive terminal. When an electron moves away from the covalent bond that produced this free electron, it will leave behind an atom with a positive charge, which we call a positive ion. The electrons moving towards one end of the crystal set up a region that has a local negative charge, as shown in Fig. 10. This negative charge sets up a potential difference between that part of the crystal and the positive terminal of the battery. In other words the attraction of the positive battery terminal causes electrons to bunch up near the end of the crystal connected to the positive terminal. The electrons are drawn from the crystal into the wire connecting the crystal to the positive terminal of the battery by this potential difference.

Meanwhile, the electrons that have left the atoms at the other end of the crystal have left behind positive ions. This sets up a region of positive charge around the end of the crystal connected to the negative terminal of the battery so there will be a potential difference between the negative terminal of the battery and this region of positive charge. This potential difference will pull electrons from the wire into the crystal. These electrons replace the free electrons that were attracted to the positive terminal of the battery.

The number of electrons leaving the crystal at the end connected to the positive terminal of the battery will be exactly equal to the number of electrons entering the crystal at the end connected to the negative terminal of the battery. Since the crystal was electrically neutral be-

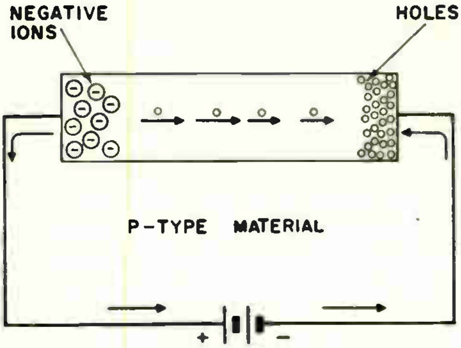


Fig. 11. P-type crystal with voltage applied to it.

fore the battery was connected and the number of electrons in it are constant, the crystal remains electrically neutral.

P-Type Material.

Conduction through P-type material is quite different from conduction through N-type material. In the P-type semiconductor, nearly all of the current is carried by holes. When a battery is applied to a P-type semiconductor, as shown in Fig. 11, the voltage causes the holes to drift towards the negative terminal. They are repelled by the positive potential applied to the one end of the material and attracted by the negative potential applied to the other end. When a hole starts moving away from the end of the material connected to the positive terminal of the battery, it moves because it is filled by an electron attracted from a nearby germanium atom.

When the hole in an accepter type atom is filled with an electron, the atom actually has one electron more than it needs to neutralize the charge on the nucleus. Thus, the atom has a negative charge, or in other words it becomes a negative ion. Negative ions that are formed near the end of the semiconductor that is connected to the positive terminal of the battery build up a region of negative charge at this end of the material. The extra electrons are drawn from these ions by the positive terminal of the battery, and a new hole is formed. These holes then drift towards the end of the semiconductor that is connected to the negative terminal of the battery, and build up a positive charge at this end of the semiconductor. This positive charge attracts free electrons from the external circuit. As a hole is filled with an electron, it disappears.

Thus in the P-type material, we have an electron flow in the external circuit from the negative terminal of the battery to the semiconductor, and from the semiconductor to the positive terminal of the battery. However, in the semiconductor itself, current flow is by means of holes, which drift from the end of the semiconductor that is connected to the positive terminal to the end that is connected to the negative terminal of the battery. Keep this point in mind, that even in the P-type material where conduction within the material is by holes (which are positive carriers) the current flow in the external circuit is by means of electrons and is in the conventional direction from the negative terminal towards the positive terminal of the battery in the external circuit.

There are several important differences between conduction in N-type semiconductors and conduction in P-type semiconductors. In both cases electrons flow from the external circuit into the crystal and then out of the crystal into the external circuit. However, in the N-type crystals, the excess electron produced when a donor atom forms covalent bonds with four germanium atoms is a free electron that can move about in the crystal. However, in the P-type material, the electrons are not free, but can move only to holes. Since a hole can capture an electron from any of its surrounding atoms, it is the hole that is free to move in any direction.

Another important difference between the N-type and the P-type materials is that a free electron moves approximately twice as fast as a hole. This affects the conductivity of the two types of semiconductor material. If we have two crystals, one an N-type and the other a P-type, if the N-type material has the same number of free electrons as the P-type has holes, the N-type will have a lower resistance because the free electrons can move approximately twice as fast as the holes in the P-type material.

SUMMARY

The important thing to remember from this section is that there are two types of carrier movement in semiconductors. The first is called diffusion and is simply a random movement of the carriers in the semiconductor material. The current flow produced by one carrier is cancelled by the movement of the other, and the resultant current flow in any direction is zero. Diffusion is the random motion of electrons or holes in a doped semiconductor due to the energy of the material.

The other type of movement we discussed is called drift. This type of conduction is produced when a potential is connected across a semiconductor. This potential can cause either electrons or holes to move within the semiconductor. In an N-type semiconductor, current flows through the semiconductor because of the movement of the free electrons produced by the donor atoms that have been added to the semiconductor material. In the P-type semiconductor, current flow through the crystal is by means of holes which are produced when an accepter-type impurity is added to the crystal.

In both cases current flow in the external circuit is from the negative terminal of the battery to the crystal and from the crystal to the positive terminal of the battery. In the N-type material, electron flow through the crystal is from the end connected to the negative terminal of the battery to the end connected to the positive terminal of the battery. In the P-type semiconductor, the holes flow from the end of the semiconductor connected to the positive terminal of the battery to the end of the semiconductor connected to the negative terminal of the battery.

The speed with which electrons move through N-type material is about twice the speed with which holes move through P-type material. Thus N-type material has better conductivity than P-type material, which means that N-type germanium will have a lower resistance than P-type germanium.

SELF-TEST QUESTIONS

(t) When an accepter-type impurity is added to a silicon or a germanium crystal, what type of carrier is produced in the crystal?

(u) What is diffusion?

(v) What is the name given to the movement of carriers in a semiconductor material when a voltage is applied across the material?

(w) What are the majority carriers in an N-type material and in what direction do they move when a voltage is applied across the material?

(x) What are the majority carriers in a P-type material and in what direction do they move through the material when a potential is applied across the material?

(y) When current is flowing through a crystal, will the crystal be charged?

(z) Is the rate of travel of electrons through N-type material the same as the rate of travel of holes through P-type material?

(aa) If you had two identical pieces of silicon and one was doped so that it was N-type material and the other doped so that it was P-type material, which would have the lower resistance?

Semiconductor Diodes

Just as there are diode tubes, there are also diode semiconductors. Some diode semiconductors are used as detectors: others are used as rectifiers in power supplies to change ac to pulsating dc. Diodes used as detectors are often referred to as signal diodes. Both germanium and silicon signal diodes are widely used. Diodes used for power rectification are almost exclusively silicon diodes. Relatively small silicon diodes can often handle considerably more current than a large rectifier tube.

A semiconductor diode is made by taking a single crystal and adding a donor impurity to one region and an accepter impurity to the other. This will give us a single crystal with a P section and an N section. Where the two sections meet, we have what is called a junction. Contacts are fastened to the two ends of the crystal so that a simple PN junction diode like the one shown in Fig. 12 is formed. For simplicity in the diagram we have represented the crystal as a box-like structure with one half being P-type material and the other half N-type material with a junction between the two sections.

This type of diode is called a junction diode. The action that takes place at the junction of the P-type crystal and the N-type crystal is what we will be most concerned with now. In order to understand how a junction diode works, you must learn something about the movement of electrons and holes near the junction. The movement of holes and

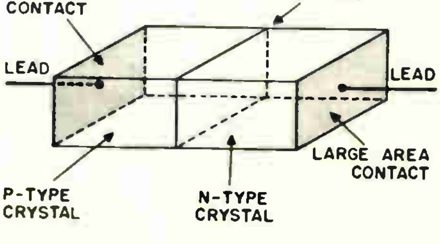


Fig. 12. Simple PN junction.

electrons will form what is called a depletion layer at the junction. Now let us see what the depletion layer is and how it is formed.

DEPLETION LAYER

Remember that in an N-type crystal there are free electrons, and in a P-type crystal there are free holes. Also remember that the electrons and holes are moving about the crystal with a random motion, called diffusion. In the PN junction diode, holes will be moving about in the P section and electrons in the N section. Some of the holes will cross over the junction from the P section into the N section and be filled by a free electron. Similarly, some of the electrons in the N-type material will diffuse across the junction and fill a hole in the P section.

When an atom in the N section loses an electron the atom becomes charged or ionized. It will have a positive charge because it will have one less electron than is needed to completely neutralize the charge on the nucleus. Thus electrons diffusing across the junction to fill a hole on the P side of the junction will leave behind atoms with a positive charge. At the same time, when an electron fills a hole on the P side, the atom will have one more electron than it needs to completely neutralize the charge on its nucleus, and therefore that atom will have a negative charge. Similarly, holes diffusing from the P side of the junction over into the N side will leave behind atoms with a negative charge. When the hole moves over to the N side, it will mean the atom into which it moves will have an electron missing and therefore it will assume a positive charge. When the hole leaves the P side of the junction because it has been filled by an electron, the atom that gains the extra electron will have a negative charge.

As a result of this diffusion across the junction, a region will build up around the junction called the depletion area. On the P side of the junction there will be an area where the holes are missing. On the N side of the junction there will be an area where electrons are missing; thus we get the name depletion layer.

The missing holes on the P side of the junction will result in a negative charge on the P side and the missing electrons on the N side will produce a positive charge on the N side of the junction. The negative charge on the P side of the junction will build up until it has sufficient amplitude to prevent any further electrons from the N side from crossing the junction to the P side. Remember that the negative charge built up on the P side of the junction will repel electrons from the negative side. Similarly, the positive charge built up on the N side of the junction will prevent holes from the P side from crossing the junction into the N-type material. Thus this area, which is called the depletion layer because it is short holes on one side and electrons on the other side, is also sometimes called the barrier layer, because the charges built up form barriers to prevent any further diffusion of holes or electrons across the junction. It is also sometimes called a potential barrier because a negative potential is built up on the P side of the junction and a positive potential is built up on the N side of the junction.

The action taking place at the junction is quite important and is illus-

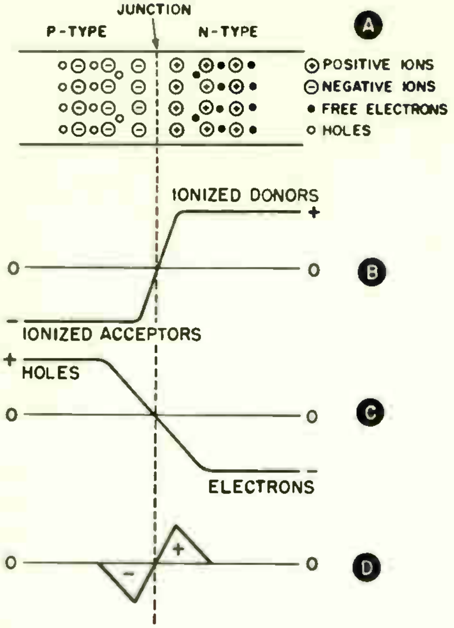


Fig. 13. (A) locations of ions and carriers at a PN junction; (B) charges at junction due to ionized impurity atoms; (C) carrier charges available; (D) resultant charges.

trated in Fig. 13A. On the P side of the junction we have shown ionized atoms that have a negative charge because the holes in these atoms have been filled by electrons. The holes have escaped and travelled or diffused across the junction into the N-type material. On the N side of the junction we have shown atoms that are ionized and have a positive charge. These atoms have a positive charge because they have lost electrons. These electrons have diffused across the junction into the P-type material. Thus we have a charged area at the junction. The negative charge on the P side of the junction prevents any further movement of electrons from the N-type material across the junction into the P-type material, and the positive charge on the N side of the junction prevents any further movement of holes from the P-type material across the junction into the N-type material.

The charge on the ions is shown in Fig. 13B. Notice that on the P side of the junction the atoms that have lost holes by gaining electrons have a negative charge. At the junction the potential drops to zero and then reverses on the N side where the ionized atoms have a positive charge because they have lost electrons.

In Fig. 13C we see the carrier charges which are available to neutralize the ionized atoms. At some distance from the junction there are holes with a positive charge. However, as we approach the junction, the concentration of these holes decreases because they are repelled away from the junction by the positive ions on the N side of the junction. On the N side of the junction at some distance from the junction we have many electrons available, but as we approach the junction, the charge drops to zero because these electrons are repelled away from the junction by the negative ions on the P side of the junction.

The resultant charges on the crystal are shown in Fig. 13D. As before, the crystal will have a tendency to remain neutral, or in other words not to have any charge. Some distance from the junction the atoms will have exactly the correct number of holes and electrons so that the net charge on the atoms is zero. As we approach the junction, the negative ions on the P side will result in an area in the crystal that has a negative charge. As we move closer to the junction, the charge will drop to zero so that at the junction itself the net charge on the atoms is zero. Then the charge builds up in a positive direction on the N side of the junction due to the ionized atoms that have lost electrons. As we move away from the junction we again reach a region where the atoms have exactly the correct number of electrons to neutralize the charges on the nucleus so the net charge in that area will be zero.

So far we have been discussing only the action of the majority carriers at the PN junction. However, there is one other important point we must consider in order to completely understand what happens at the junction. You will remember some time ago that we mentioned that holes and electrons are in a continuous state of motion in the crystal due to the energy of the crystal. For example, even at room temperature, the crystal contains a certain amount of heat energy and this energy is sufficient to cause motion of both electrons and holes. In the N-type material an electron will leave an atom creating a hole. This hole will be filled by an electron from another atom. Thus we have the continual formation of hole-electron pairs. Away from the junction, this formation of hole-electron pairs does not have any effect on the carrier concentration in the crystal. In other words, the holes will remain the majority carriers in the P-type region, and the electrons will remain the majority carriers in the N-type side of the crystal.

However, as we mentioned previously, both holes and electrons are involved in conduction at all times. There are minority carriers in both regions - holes in the N region and electrons in the P region. The holes produced in the N region near the junction will be attracted by the negative ions on the P side of the depletion layer at the junction and pass across the junction. These holes will tend to neutralize the ions on the P side of the junction. Similarly, free electrons produced on the P side of the junction will pass across the junction, and neutralize positive ions on the N side of the junction. This is an example of intrinsic conduction, conduction due to the formation of hole-electron pairs, and as we mentioned, this type of conduction is undesirable.

Now let us consider what happens due to the minority carriers crossing the junction. Holes crossing the junction from the N-type material to the P-type material tend to neutralize the negative ions on the P side of the junction. Similarly, electrons traveling from the P side of the junction to the N side of the junction tend to neutralize the positive ions on the N side of the junction. This flow of minority carriers across the junction weakens the potential barrier in the region around the atoms they neutralize. When this happens, the majority carriers are able to cross the junction at the location of the neutral atom. This means that the holes from the P side will cross over to the N side, and electrons from the N side will cross over to the P side.

The result is that we have both holes and electrons crossing the junction in both directions. The hole that crosses from the N side to the P side due to intrinsic conduction permits a hole to cross from the P side to the N side by diffusion. Similarly, an electron that crosses the junction from the P side to the N side due to intrinsic conduction permits another electron to go from the

N side to the P side by diffusion. The result of the holes and electrons crossing the junction in both directions is that these movements cancel each other, and the charge on the atoms at the junction remains the same. This movement of holes and electrons in both directions contributes nothing towards the net charge or current flow through the junction. However, the flow across the junction will produce a certain amount of heating; it will in effect use up a percentage of the total capacity of the junction to pass current so that the net result is to reduce the amount of useful current the diode can pass.

BIASED JUNCTIONS

If a battery is connected to the ends of a PN junction diode, the battery potential will bias the junction. If we connect the battery so that its polarity aids the flow of current across the junction, we call it a "forward-biased junction", whereas if we connect the battery so that the polarity opposes the flow of current across the junction, we say that it is a "reverse-biased junction". In both cases there will be some current flow through the junction, but as you might expect, with forward bias the current flow will be higher.

In order to understand how transistors work, you must understand both conditions of bias. You will study each condition separately, because the action that occurs at the junction is quite different in the two cases. In the operation of transistors both types of bias are used, and therefore it is important that you understand what happens in each case.

Forward Bias.

When we connect a battery to a junction diode with the polarity such that it aids the movement of majority carriers across the junction, we say that the diode is forward biased. A forward-biased junction is shown in Fig. 14. Here the positive terminal of the battery is connected to the P-type section and the negative terminal of the battery is connected to the N-type section. Now let us consider what happens to the depletion layer at the junction of the P and N-type material when the battery voltage is applied.

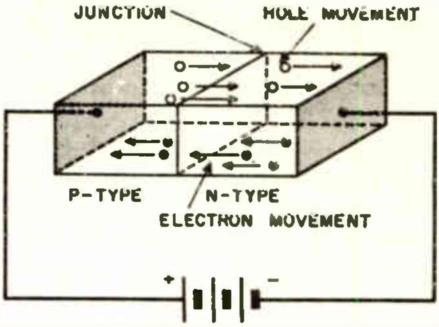


Fig. 14. Forward-biased junction.

The positive voltage connected to the end of the P-type crystal will repel holes towards the junction and attract electrons from the negative ions near it. The combination of holes moving towards the junction to neutralize charged negative ions on the P side of the junction and electrons being taken from the negatively charged ionized accepter atoms tends to neutralize the negative charge on the P side of the junction.

On the N side of the crystal, the negative terminal of the battery repels electrons towards the junction. These electrons tend to neutralize the positive charge on the donor atoms at the N side of the junction. At the same time the negative potential at the N side of the crystal attracts holes away from the charged positive ions on the N side of the junction. Both of these actions tend to neutralize the positive charge on the donor atoms at the junction.

The effect of the battery voltage is to reduce the potential barrier at the junction and allow more majority carriers to cross the junction. This means that we will have more electrons flowing from the N-type material across the junction to the P-type material and to the positive terminal of the battery and more holes traveling from the P-type material across the junction to the N-type material and towards the end of the crystal connected to the negative terminal of the battery. You know that we already had a certain number of intrinsic minority carriers crossing the junction, but now the majority carriers outnumber them, so there will be a steady current flow from the negative battery terminal, through the N-section, across the junction and through the P-section, to the positive battery terminal.

Placing a forward bias on a junction diode drives majority carriers back into the depletion layer and allows conduction across the junction. If the battery voltage is increased, more carriers will arrive at the junction and the current flow will increase. Eventually, if we continue to increase the battery voltage, we will reach a point where all the charges at the junction are neutralized. When this happens, the holes will fill the P-type region right up to the junction; electrons will fill the N-type region up to the junction; and the only limit to current flow through the diode will be the resistance of the material on the two sides of the junction.

It is important for you to remember that in a forward biased junction conduction through the crystal will be by the majority carriers. Any intrinsic conduction across the junction will be by minority carriers and this will subtract from the total current flow across the junction. Increasing the forward bias will increase the current flow across the junction until the point is reached where all the charges at the junction are neutralized, at which time the potential barrier will disappear, and current flow across the junction will be unhindered by any potential across the junction.

Reverse Bias.

If we reverse the battery connections we will have what is known as reverse bias. This condition is shown in Fig. 15.

With a reverse bias applied to a junction diode, the negative terminal of the battery will be connected to the P-type section, and will attract holes away from the junction, and increase the shortage of holes on the P side of the junction. At the same time the positive terminal of the battery is connected to the N-type section of the crystal and this

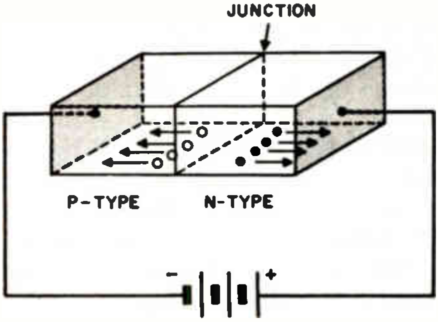


Fig. 15. Reverse-biased junction.

terminal will attract electrons away from the junction and increase the shortage of electrons on the N side of the junction. This movement of holes and electrons away from the junction will in effect result in an increased potential barrier at the junction. The increase in potential barrier occurs because there will be fewer holes on the P side of the junction to neutralize the negative ions and fewer electrons on the N side to neutralize the positive ions formed on this side of the junction. The increase in potential barrier will help prevent any further current flow across the junction due to majority carriers.

The current flow across the barrier, however, is not zero because we will still have minority carriers crossing the junction. Holes forming in the N side of the depletion layer will be attracted by the negative potential applied to the end of the P-type section of the crystal, and electrons breaking loose from their nuclei in the P side of the depletion layer will be attracted by the positive voltage applied to the end of the N-type section of the crystal.

We had this situation when there was no bias applied to the junction. Holes from the N side would cross over to the P section, and electrons from the P side would cross over to the N section. However, when there was no bias applied to the crystal, these minority carriers would neutralize ions near the junction and allow the majority carriers to cross the junction. However, since the minority carriers are now attracted away from the junction by the potential applied to the crystal, all of the minority carriers do not remain near the junction to neutralize charged atoms so they no longer allow the passage of an equal number of majority carriers in the opposite direction. This means that the flow of minority carriers across the junction is not fully offset by a flow of majority carriers in the opposite direction. Therefore, there will be a small current flow across the junction due to the minority carriers crossing the junction. This current flow is very small and nearly constant at all normal operating voltages in signal diodes and power rectifier diodes. However, as you will see later, there are certain types of diodes where this reverse current can increase quite rapidly even at low voltages.

It is important to realize that when a reverse bias is applied to a junction diode, the bias increases the potential difference across the junction and makes it more difficult for majority carriers to cross the junction. However, some minority carriers will still cross the junction with the result that there will be a small current flow across the junction due to the minority carriers.

COMPARISON OF JUNCTION DIODES AND VACUUM TUBES

Although the operation of junction diodes designed for use as rectifiers is quite different from the operation of vacuum tubes, they can perform identical tasks and therefore some comparison of the most important characteristics of both is in order.

When there is no voltage applied to a junction diode, the net current flow across the junction is zero. On the other hand, in a vacuum tube, even though there may be no voltage applied to the plate of the tube, some of the electrons will leave the cathode with sufficient velocity to travel across the space between the cathode and the plate and strike the plate. This will result in a small current flow from the cathode to the plate of the tube even though there may be no voltage applied to the plate of the tube.

We can consider applying a positive voltage to the plate of a vacuum tube and a negative voltage to the cathode as being similar to placing a forward bias on a junction diode. Under both circumstances there will be a current flow through the diode. In this respect the two are similar.

When the voltages applied to the diode vacuum tube are reversed so that there is a negative voltage applied to the plate and a positive voltage to the cathode, there will be no current flow at all through the tube. The negative potential on the plate of the tube will repel electrons from the plate. This reverse voltage situation is similar to a reverse bias across a junction diode. However, when we place a reverse bias across a junction diode, there will be some current flow across the junction due to the conduction by minority carriers. As long as the breakdown voltage of the junction diode is not exceeded, this current will be very small and almost constant. In a good diode, it is so small it can be ignored.

We can summarize the characteristics of diode vacuum tubes and junction diodes as follows: with forward bias both the tube and junction diodes will conduct. With reverse bias, the tube will not pass current; the junction diode will pass a small current. With no bias, the tube will pass a small current; the junction diode will not.

ZENER DIODES

In junction diodes designed for use as rectifiers we must be careful not to exceed the rated reverse voltage of the diode. In other words, if we place too high a reverse bias across the junction, the junction will break down, a very high current will flow across the junction for a short while, and the diode will be destroyed. However, in some diodes we make use of this reverse current due to minority carriers. In diodes of this type both the P section and the N section are doped quite heavily. The junction between the P section and the N section is considerably larger than the junction of the rectifier-type diode, so that when the diode begins to pass current in the reverse direction, it can pass it over a larger area and thus avoid destroying the diode. This type of diode is used as a voltage reference and is referred to as a voltage-reference diode or a Zener diode.

In the Zener diode, the current remains small with low reverse voltages. At a certain voltage, called the breakdown voltage, the current will increase rapidly with any further increase in voltage.

The breakdown voltage can be varied by varying the diode material and construction. Zener diodes can be made with a breakdown voltage as low as 1 volt, up to breakdown voltages of several hundred volts. The current that can pass through any Zener diode before the diode will be damaged will depend upon the junction area and the methods used to keep the diode cool.

In a circuit where a Zener diode is used, it will be used as a voltage reference or a voltage regulator. As the reverse voltage across the diode

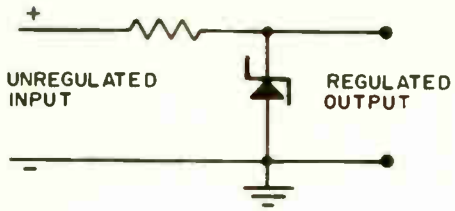


Fig. 16. Circuit using Zener diode as a voltage regulator.

increases, a very small reverse current will flow, and the value of this current will remain essentially constant until the breakdown voltage is reached. At that voltage, any further increase in voltage will result in a large increase in current across the junction. This large increase in current tends to produce a voltage drop in other components in the circuit so that the voltage across the diode will remain essentially constant. Thus a Zener diode can be used as a voltage regulator in a circuit such as shown in Fig. 16. If the input voltage tends to rise, the current through the diode will increase. This increase in current will increase the voltage drop across the resistor so that the output voltage will remain essentially constant. The fact that with even a very small increase in voltage the current through the diode will increase substantially means that the voltage across the diode will remain almost constant.

In some other applications the diode may be used as a reference voltage. This simply means that a Zener diode with a given breakdown voltage is used in a circuit like Fig. 16. The voltage applied to the diode will remain essentially constant. In some circuits, we may compare the voltage across a resistor or another part with the voltage across the Zener diode.

TUNNEL DIODES

A tunnel diode is a highly doped junction diode made either of germanium or gallium arsenite. Both the N region and the P region of the diode are very highly doped. As a result of the high doping, the depletion region around the junction is extremely narrow. Because of the narrow depletion region, holes and electrons can cross the junction by more or less tunneling from one atom to another. The exact action of the charges crossing the junction is somewhat difficult to visualize, but the characteristics of the tunnel diode are comparatively simple. With a reverse bias across the junction, current across the junction increases quite rapidly. If the reverse bias is dropped to zero the current will drop back to zero. If the forward bias, starting at zero and gradually increasing, is placed across the junction, current flow across the junction will increase at essentially the same rate as it increased with a negative bias. The current across the junction will increase quite rapidly as the forward bias is increased until a rather sharp peak is reached. If the forward bias is increased beyond this point, then the current begins to decrease.

As the forward bias is increased still further, the current across the junction decreases, forming a curve such as shown in Fig. 17. This decreasing current, with increasing voltage, results in a negative resistance characteristic. It might be difficult to visualize what a negative resistance is, but you will remember from Ohm's Law that re-

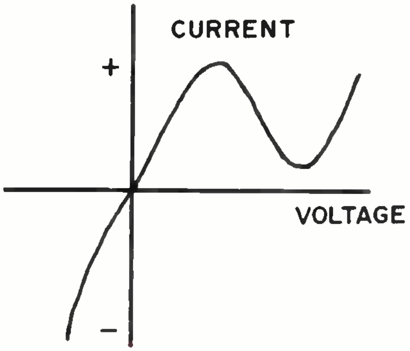


Fig. 17. Voltage-current relation in a tunnel diode.

sistance is equal to voltage divided by current. In a circuit where we have resistance, if the resistance is constant and the voltage increases, then the current must increase; and similarly if the voltage decreases, the current must decrease. Here in the tunnel diode we have a region where the opposite happens. If the voltage increases, the current decreases and if the voltage decreases, the current increases. Thus we have something in the circuit that is giving us the opposite effect of resistance; we call this negative resistance. You will remember that resistance in a circuit introduces losses. It is the resistance in a resonant circuit that prevents a resonant circuit from continuing to oscillate once it has been excited into oscillation. However, if we can put something with negative resistance in the circuit, for example a tunnel diode, since it has the opposite effect of resistance, then the circuit should continue to oscillate. Tunnel diodes can be used for this purpose.

At the present time, tunnel diodes have not appeared in the commercial entertainment-type equipment. However, it is probably just a matter of time until they are used; therefore you should at least have some basic knowledge of what the tunnel diode is.

P-I-N DIODES

The p-i-n diode, which is an abbreviation from positive-intrinsic-negative, is a new diode which is used in a somewhat different manner from the diodes you have studied previously. Rather than being used as a detector or rectifier, this diode is used primarily as a variable resistor. It is a special type of diode, and its resistance can be controlled by applying a dc bias to it. With a reverse bias across the diode, it has a very high resistance. With no bias, its resistance drops to about 7000 ohms, and with forward bias it drops to a comparatively low value.

The diode is particularly useful in circuits where the strength of a signal must be controlled. Its first commercial use has been in fm equipment and it is used in order to prevent extremely strong fm signals from causing overloading in the fm receiver. A dc bias is applied to the diode and the amplitude of the bias depends upon the strength of the signal. When a very strong signal is applied, the reverse bias applied to the diode increases so that the resistance of the diode increases. This reduces the strength of the signal fed to the mixer and i-f stages in the receiver and thus prevents overloading, particularly in the last stage of the receiver.

At this time p-i-n diodes are not widely used in commercial applications, but you should be aware of how the diode is used, because it is quite likely that it will be widely used in the future.

POINT-CONTACT DIODE

Another semiconductor diode is the diode detector used in many TV receivers. This detector is a point-contact diode. A cut-away view of a point-contact diode is shown in Fig. 18 along with the schematic symbol.

The point-contact diode is made of a small piece of either N-type or P-type germanium or silicon. N-type germanium or silicon is used more often than P-type. In manufacturing a diode of N-type material, a large contact is fastened to one side of the crystal. A thin wire, called a catswhisker, is attached to the other side of the crystal. When the catswhisker is attached to the N-type crystal, a small region of P-type material is formed around the contact as shown in Fig. 19. Thus we have a PN junction that performs in much the same way as the junctions we have already discussed.

The characteristics of the point-contact diode under forward and reverse bias are somewhat different from those of the junction diode. With forward bias the resistance of the diode is somewhat higher than that of a junction diode. With reverse bias the current flow through a point-contact diode is not as independent of the voltage applied to the crystal as it was in the junction diode. In spite of these disadvantages, the point-contact diode makes a better detector than the junction diode, particularly at high frequencies because the point-contact diode has a lower capacity than the junction diode.

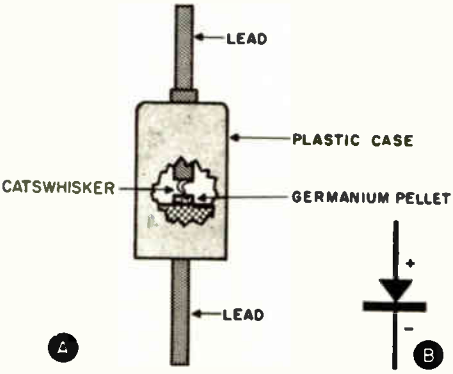


Fig. 18. (A) cut-away view of crystal rectifier. (B) schematic symbol of it.

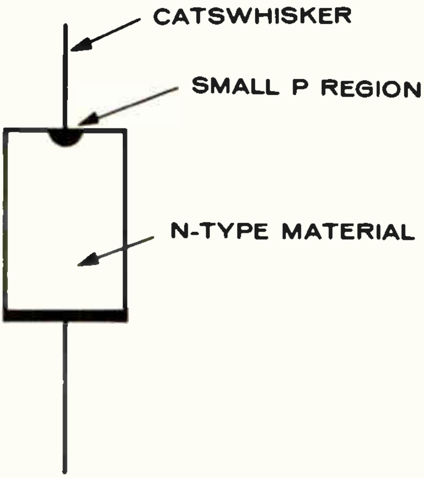


Fig. 19. Sketch of a point-contact diode showing where the P-type germanium is formed around the catswhisker.

SUMMARY

Again this is a very important section, so you should review it before going on to the next section. Make sure you understand what the depletion layer is and why it is formed. Also be sure you understand the movement of holes and electrons across a PN junction when no voltage is applied to the junction.

Current flow across the junction with both forward and reverse bias is important. With forward bias current flow across the junction is by majority carrier, and with reverse bias it is by minority carrier.

SELF-TEST QUESTIONS

(ab) What are the two principal uses of semiconductor diodes?
(ac) What is the depletion layer?
(ad) What do we mean by the potential barrier?
(ae) Does the crystal develop an overall charge as a result of diffusion across the junction?
(af) Do the minority carriers crossing the junction have any adverse effect on the diode?
(ag) What do we mean when we say the junction is forward biased?
(ah) What do we mean when we say a junction is reverse biased?
(ai) What is the difference between vacuum-tube diodes and semiconductor diodes insofar as current flow through the diode is concerned when no voltage is applied?
(aj) What is the difference between current flow in a semiconductor diode and a vacuum tube under reverse voltage conditions?
(ak) What is a Zener diode, and what is it used for?
(al) What is a tunnel diode?
(am) What is a p-i-n diode?

Semiconductor Triodes

Even though a junction diode will pass current in both directions, it passes current in one direction much better than it does in the other, and therefore it can be used as a detector. The tunnel diode can be used as an oscillator, and in some special circuits as an amplifier; however, its usefulness in these applications is limited. In most cases, the semiconductor diode is like the vacuum-tube diode; it is more or less useless insofar as amplifying a signal is concerned. In order to amplify a signal, a three element semiconductor is needed. Three element semiconductors that are capable of amplification are called transistors.

There are a number of different types of transistors in use today. The characteristics of the different types vary appreciably, but if you understand the operation of one type, you can understand how the others work without too much difficulty. We started our explanation of semiconductor devices with a junction diode, so we will start our study of triode semiconductors with a study of the junction transistor. You'll find that most of the transistors you will study operate in a manner similar to the basic junction transistor. The most notable exception to this is the field-effect transistor which you will study later in this lesson.

JUNCTION TRANSISTORS

Both germanium and silicon are used in the manufacture of junction transistors. A triode-junction transistor is made up of single semiconductor crystals with three different regions. The center region is made up of one type of germanium or silicon, and the two end regions are made up of the other type of germanium or silicon. In other words, in one type of junction transistor the center has had accepter-type region impurities added and the two end regions have had donor-type impurities added. In the other type of junction transistor, the center region has had donor-type of impurities added and the two end regions have had accepter-type impurities added.

The center region of the transistor is called the base. This is usually a comparatively thin region. One of the end sections is called the emitter and the other end section is called the collector.

If the center section of the crystal has been treated with donor-type impurities, then the center section becomes N-type germanium in the case of a germanium transistor or N-type silicon in the case of the silicon transistor. In this case, the two end sections will be treated with accepter-type impurities and they will both become P-type germanium or P-type silicon. We call this type of transistor a PNP transistor. We can have both germanium PNP and silicon PNP transistors. An example of this type of junction transistor is shown in Fig. 20A along with the schematic symbol used to identify it.

The other type of junction transistor is an NPN type. This type of transistor is produced by treating the center section with an accepter-

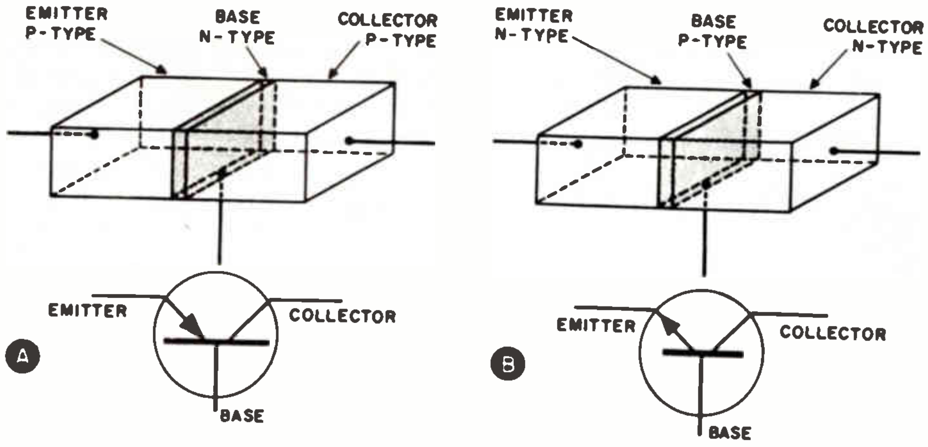


Fig. 20. (A) shows a PNP junction transistor and its schematic symbol. (B) shows an NPN junction transistor and its schematic symbol.

type impurity to produce P-type germanium or silicon, and the two end sections with a donor-type of impurity to produce N-type germanium or silicon. This is the type of junction transistor shown in Fig. 20B along with the schematic symbol for it. As in the case of the PNP transistor, we can have either an NPN germanium transistor or an NPN silicon transistor.

Notice that the schematic symbols for the PNP transistor and the NPN transistor are different. In the PNP transistor the arrow used to represent the emitter points down toward the base, whereas in the NPN transistor the arrow on the emitter points up away from the base. Thus on a schematic diagram of a piece of equipment using junction transistors, you can tell from the direction in which the arrow is pointing whether the transistor is a PNP or an NPN transistor.

There are several different ways of manufacturing junction transistors, and often you hear these transistors referred to by the manufacturing method used. For example a junction transistor might be called a grown junction, a fused junction, an alloy junction or a diffused junction. All these names simply describe the manufacturing process used to make the transistor. They are all junction transistors and all operate on the same basic principle. This does not mean to imply that the characteristics of all junction transistors are the same; they are not. There are wide differences in characteristics just as there are in various triode vacuum tubes.

To understand how junction transistors work, you must understand junction diodes. Because it is so important that you understand the formation of the depletion layers at the junctions we will review the explanation of what happens at the junctions in explaining the junction transistors. The big difference between the junction transistor and the junction diode is that in the transistor there are two junctions close together in the same crystal. One of these junctions is biased in the forward direction and the other in the reverse direction and the presence of one junction affects the operation of the other.

PNP TRANSISTORS

In transistor operation, the emitter-base junction is always biased in the forward direction and the collector-base junction is biased in the reverse direction. Each of the two junctions by itself behaves just like the PN junction already described.

Let us consider what happens in the PNP transistor before any voltages are applied to the transistor.

At the junctions, holes from the P-type emitter section and the P-type collector diffuse across the junctions into the base. At the same time, electrons from the base diffuse across the junctions into both the emitter and the collector. The holes diffusing into the base place a positive charge on the atoms near the junctions. Similarly the electrons diffusing from the base into the emitter on one side of the base and the collector on the other side of the base place a negative charge on the atoms on the emitter and collector sides of the junctions. These charged atoms, which are called ions, will repel electrons and holes from the region of the junctions. The positively charged ions in the base will repel holes in the P sections away from the junctions. Similarly, the negatively charged ions in the emitter and collector will repel electrons away from the junctions in the base. Thus we have two depletion layers formed, one at the emitter-base junction and the other at the base-collector junction.

You will remember that when we discussed the junction diode, we mentioned that hole-electron pairs will be formed in the depletion region. The minority carriers formed in each section can cross over the junction. For example, the electrons released in both the emitter and the collector regions will cross the junctions into the base. These electrons will neutralize a few ions in the base region. When these ions are neutralized they will allow majority carriers from the emitter and collector to cross the junctions. In other words, there will be holes from the emitter and holes from the collector crossing the junctions into the base. Similarly, holes, which are the minority carriers in the base region (and are formed in the depletion layer) will cross the junctions into the emitter and collector. When these holes cross the junctions they will neutralize some of the nega-

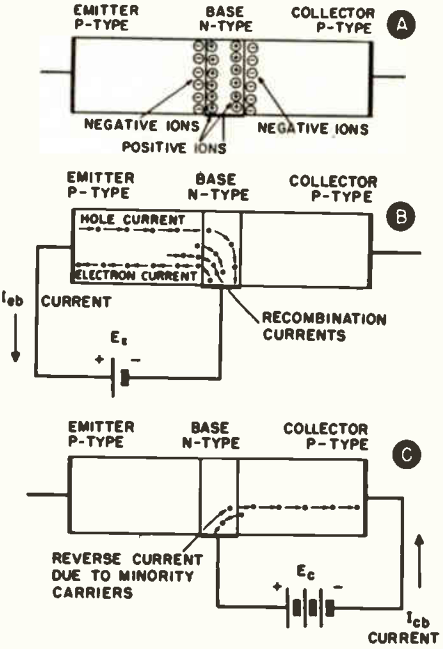


Fig. 21. (A) the formation of ions at the junctions of a PNP transistor. (B) the current flow in the emitter-base circuit and (C) in the collector-base.

tively charged ions in the emitter or collector region and allow some electrons to flow from the base into either the emitter or the collector. Thus, because of the intrinsic conduction due to hole-electron pairs being formed in the depletion region there will be some flow of carriers across the junction. However, the flow of majority carriers across the junction will be exactly equal to the flow of minority carriers across the junction so that the net current flow across each junction will be zero.

The potential barriers formed at the junction regions are shown in Fig. 21A. Notice that the charges formed at the junction are similar to those formed at a junction diode; we simply have two junctions to consider in a transistor.

Now when we place a forward bias between the emitter and the base we have an arrangement like that shown in Fig. 21B. Here the positive voltage applied to the end of the P-type emitter repels holes towards the junction. These holes tend to neutralize the negative charge on the ions on the emitter side of the junction. The holes are formed at the end of the P-type section by electrons being taken out of this section by the positive potential applied to it. At the same time the positive potential applied to the emitter attracts the electrons that have given the ions on the P side of the junction their negative charge. This also weakens the negative charge on the emitter side of the junction.

At the base, which is connected to the negative side of the battery, the holes will be attracted toward the negative terminal of the battery, and electrons will be pushed towards the depletion layer. The pulling of holes away from the depletion area and pushing electrons into the depletion area tends to neutralize the charge on the base side of the junction.

The net effect of biasing in a forward direction is to neutralize the charges on each side of the junction and allow current to flow across the junction. Current flow is by majority carriers: electrons from the N-type base region and holes from the P-type emitter region.

Thus in the emitter-base circuit we have electrons flowing from the negative terminal of the battery to the base, through the base, across the junction, and through the emitter to the positive terminal of the battery. At the same time we have holes being produced because electrons are being pulled out of the P-type emitter by the positive potential applied to it. The holes will move through the emitter, across the junction into the base and to the point where the base is connected to the negative terminal of the battery. At this point they will pick up electrons and disappear.

Not all the electrons going from the base to the emitter will reach the positive terminal of the battery. Some of these electrons will recombine with holes in the emitter. Similarly, some of the holes traveling from the emitter into the base will pick up an electron in the base. This current flow across the junction is called a recombination current, and the transistor is designed to keep this current as low as possible. In other words we want the holes and electrons crossing the junction to reach the terminals connected to the battery.

Now let us consider the other junction, the base-collector junction. This junction is reverse biased as shown in Fig. 21C. Here again we have a depletion layer at the junction. Also we have minority carriers being formed in the depletion layer. However, holes that are formed in the base will cross the junction and then instead of neutralizing a negatively charged atom near the junction in the collector, these holes will be attracted by the negative potential applied to the collector. Similarly, electrons formed in the depletion layer of the P-type collector will cross the junction and be attracted by the positive potential applied to the base. Thus we have a current flow due to the minority carriers. Electrons in the depletion layer of the collector section will cross the junction and flow through the base to the positive terminal of the battery. Meanwhile electrons from the negative terminal of the battery will fill holes that are moving from the base, across the junction, and through the collector to the negative terminal.

Thus you can see that while we have a current by majority carriers due to the forward bias applied between the emitter and the base, we also have a small current flowing through the base-collector circuit by minority carriers due to the reverse bias applied between the base and the collector. Now let us see how the two junctions affect each other.

A transistor with both biased junctions is shown in Fig. 22. Here we have a number of different currents flowing. In the emitter-base circuit we have current flowing due to the forward bias applied between these two. Electrons will flow from the negative terminal of the battery into the base, across the junction, and through the emitter to the positive terminal of the battery. We will also have some holes formed in the P-type emitter section due to electrons being pulled out of this section by the positive terminal of the battery. Some of these holes will cross the junction into the N-type base where they will pick up an electron and disappear. This current is called the recombination current.

Many of these holes will cross the base and flow through the collector, because the negative terminal of the battery connected between the base and collector will attract them. This movement of holes accounts for most of the current flow in the emitter and collector circuits. Remember that holes are being continually formed in the P-type emitter because electrons are

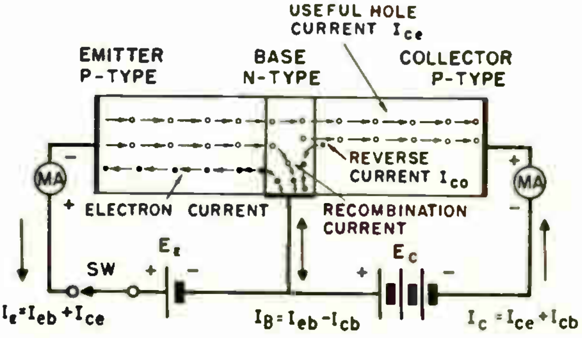


Fig. 22. Current flow and carrier movement in a PNP junction transistor.

being pulled out of the emitter by the positive potential applied to it. These holes will continually move through the emitter, and into the base. Here some of them will combine with electrons and disappear, but the majority of them will flow through the collector to the negative terminal of the collector where they will be filled by electrons and disappear.

Another current that will flow is reverse current I_{CO} that flows in the base-collector circuit. This is due to the formation of minority carriers in the depletion layer.

Thus we have four currents flowing in the PNP junction transistor. The largest of these currents is due to the movement of holes from the emitter through the base into the collector to the negative terminal of the battery connected to the collector. We have in addition to this current three small currents flowing. We have the current due to the electron movement from the negative terminal of the emitter-base battery into the base, across the junction and through the emitter to the positive terminal of this battery. We have the recombination current due to holes combining with electrons in the base, and we have the reverse current due to hole-electron pairs being formed in the depletion layer of the base-collector junction. The directions of the different movements of holes and electrons are marked in Fig. 22.

NPN TRANSISTORS

Although the operation of the NPN transistor is somewhat different from that of the PNP type, if you understand how the PNP transistor works, you should have no difficulty understanding the NPN. Again, we can start our study of this type of transistor by considering what happens at the junctions, remembering that the action at the junction is similar to the action we studied at the simple PN diode junction.

Let us first consider the action of the holes and electrons before any voltages are applied to the transistor. The charges that will be built up are shown in Fig. 23A. Remember that holes from the base will diffuse across both junctions into the emitter and the collector. Similarly electrons from the emitter and electrons from the collector will diffuse across the junctions into the base. The holes and electrons diffusing across the junctions will charge atoms near the junction. Holes crossing the junctions into the

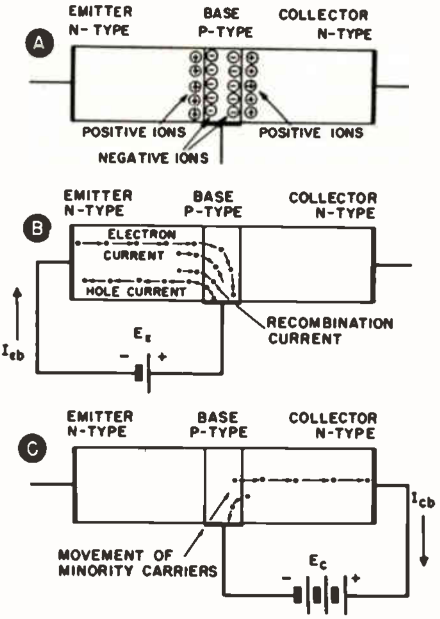


Fig. 23. (A) the formation of ions at the junctions of an NPN transistor. (B) the current flow in the emitter-base circuit and (C) in the collector-base circuit.

emitter and the collector will ionize the atoms on the emitter and collector sides of the junctions so that they will have positive charges. Similarly, electrons diffusing across the junctions into the base will ionize atoms in the base near the junctions so that they will have negative charges. Thus we will have potential barriers at the junctions. This is the same kind of potential barrier that we found existed across the PN junction in a diode.

The positively charged ions on the emitter and collector sides of the junctions will force holes in the base away from the junction. Similarly the negatively charged atoms on the base side of the junctions will force electrons in the emitter and collector away from the junction so that at the junctions we have a depletion layer.

Now let us consider what happens when we apply a forward bias between the emitter and the base by connecting a battery between the two as shown in Fig. 23B. Notice that the negative terminal of the battery is connected to the end of the emitter, and the positive terminal is connected to the base.

Now, several things happen. The negative potential applied to the emitter will force electrons toward the junction. At the same time the negative potential will attract holes away from the junction. Both of these actions tend to neutralize the positively charged ions on the emitter side of the junction. At the same time the positive terminal of the battery that is connected to the base will attract electrons away from the negatively charged atoms on the base side of the junction. In addition, the positive potential will repel holes towards the junction so that these two actions tend to neutralize the charge on the base side of the junction.

Once the potential barrier at the junction is weakened, electrons can flow from the negative side of the battery into the emitter, through the emitter, and across the junction into the base and from the base to the positive side of the battery. At the same time the positive terminal of the battery can extract electrons from the base, forming holes. Holes are then repelled toward the junction, across the junction, and through the emitter toward the end of the emitter that is connected to the negative terminal of the battery. Here the holes will pick up electrons and disappear. Thus we have a current flow through the emitter-base circuit as shown in Fig. 23B.

Now let us consider what happens when we apply a reverse bias between the base and the collector. Here the negative potential applied to the base will pull holes away from the junction, and the positive potential applied to the collector will pull electrons away from the junction. Thus the negative charge on the base side of the junction will be increased, and the positive charge on the collector side of the junction will be increased so that the potential barrier at the junction will be increased. This will prevent any current flow through the base-collector circuit due to the majority carriers.

At the same time electrons, which are minority carriers, will break loose from their nuclei in the depletion layer on the base side of the junction and will be attracted by the positive potential applied to the collector. They will cross the junction and flow through the collector to the terminal connected to the positive side of the battery, as shown in Fig. 23C. At the same time holes formed on the collector side of the junction in the layer will be attracted by the negative terminal of the battery, and hence will cross the junction and flow over into the base and toward the negative terminal of the battery. Here they will pick up an electron and disappear.

Thus we will have a current flow in the base-collector circuit due to the minority carriers. This is the same situation that we had in the reverse biased base-collector circuit of the PNP transistor.

Now let us see what happens when bias voltages are applied across both junctions of the complete NPN junction transistor as shown in Fig. 24. Considering first the emitter-base circuit, we have electrons flowing from the negative terminal of the battery to the N-type emitter. Here the electrons flow through the emitter, across the junction, and into the base. Some of these electrons reaching the base will recombine with holes in the base. This is called the recombination current. However, the majority of the electrons reaching the base will be attracted by the positive potential applied to the collector and hence will flow through the base across the base-collector junction and through the N-type collector to the positive terminal of the battery in the base-collector circuit.

At the same time the positive terminal of the battery in the emitter-base circuit is connected to the base, and this potential will pull electrons out of the P-type base, producing holes. These holes will then cross the junction into the emitter, and they will be attracted by the negative potential applied to the emitter and hence will flow through it to the end connected to the negative terminal of the battery. Here they will pick up an electron and disappear.

At the same time, in the base-collector circuit we will have a reverse current flowing due to the minority carriers. Holes appearing in the collector side of the depletion layer will cross the junction into the base and flow to the base terminal connected to the negative terminal of the battery, biasing the base-collector junction. Here each hole will pick up an electron and disappear. Electrons in the depletion layer on the base side of the junction will be attracted by the positive potential applied to the end of the collector. Hence they will cross the junction and flow toward the positive end of

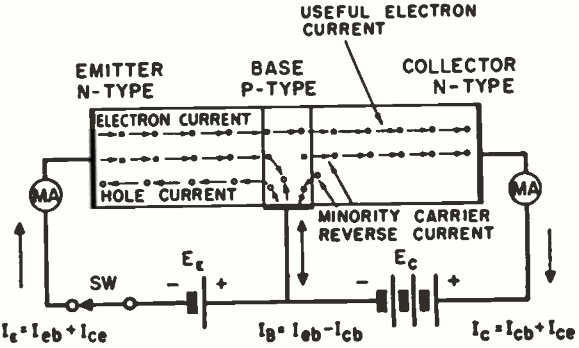


Fig. 24. Current flow and carrier movement in an NPN junction transistor.

the collector and from there to the positive terminal of the battery connected between the base and the collector.

Of these different currents flowing, the important and useful current flow is the flow of electrons from the emitter through the base to the collector. Since this is the useful current, we are interested in making this as large as possible in comparison to the other currents flowing across the emitter-base junction. Thus, the recombination current, which is due to electrons from the emitter crossing into the base and recombining with the holes, serves no useful purpose and should be kept as low as possible. This is accomplished by adding more donor atoms to the emitter than accepter atoms to the base. Thus there will be many more free electrons in the emitter than there will be holes in the base and the recombination current will be kept quite small.

Also, since there are a limited number of holes in the base compared to the number of electrons in the emitter, the number of holes crossing from the base to the emitter is also kept low in comparison to the number of electrons crossing from the emitter into the base. In a good transistor, over 95% of the electrons that cross the emitter-base junction flow to the collector.

Notice the differences and the similarities between the PNP and the NPN transistors. In both cases the emitter-base junction is forward biased and the base-collector junction is reverse biased. However, the battery connections must be reversed to provide the biases. In other words, with the PNP transistor the battery used to bias the emitter-base junction is connected with the positive terminal to the emitter and the negative terminal to the base. With the NPN transistor, the negative terminal of the battery is connected to the emitter and the positive terminal to the base. However, both are forward biased because in each case the positive terminal of the battery is connected to the P-type germanium and the negative terminal to the N-type germanium.

The base-collector junction of both transistors is reverse biased. In the PNP transistor, the positive terminal of this battery is connected to the base and the negative terminal to the collector; whereas in the NPN transistor, the negative terminal is connected to the base, and the positive terminal to the collector. Again, however, in both cases the positive terminal is connected to the N-type germanium and the negative terminal to the P-type germanium.

Also notice that in the PNP transistor the useful current flow is by means of holes, whereas in the NPN transistor the useful current flow is by means of electrons.

SELF-TEST QUESTIONS

(an) What is the base region of a transistor?

(ao) What two materials are widely used in the manufacture of transistors?

(ap) What two types of junction transistors are widely used?

(aq) What type of bias is used across the emitter-base junction in a transistor?

(ar) What type of bias is used across the base-collector junction of a transistor?

(as) Is the base region of a transistor usually a thick region or is it thin?

(at) Draw a diagram of a PNP transistor and show how the batteries are connected to place the correct bias across the two junctions.

(au) Draw a diagram of an NPN transistor and show how the batteries are connected to provide the correct bias across both junctions.

(av) What are the useful current carriers in a PNP transistor?

Semiconductor Types

There are two basic types of transistors that you will run into continuously. You are already familiar with these two types; they are the NPN transistor and the PNP transistor. However, these transistors are made in a number of different ways and the manufacturing processes result in transistors with different characteristics. In this section we are going to briefly discuss some of the important types and characteristics. We don't expect you to remember all these details; the important thing for you to remember is that they are basically either NPN or PNP transistors and operate in the same way as those we have discussed previously.

Also in this section of the lesson we'll discuss two other important semiconductor devices, the field-effect and unijunction transistors.

GROWN-JUNCTION TRANSISTORS

The first commercially available junction transistors were of the grown-junction type. This type of transistor is made from a rectangular bar cut from a germanium crystal that has been grown. Suitable impurities are added so that NPN regions such as those shown in Fig. 25 are formed. The base of the transistor is usually located midway between the two ends. Suitable contacts are then welded to the emitter, base and collector regions.

Of course, the actual bar of semiconductor material used is quite small. The emitter and the collector are considerably larger than the base; the base is kept as thin as possible and may have a thickness of less than .001".

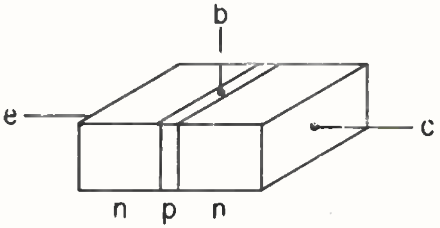


Fig. 25. A grown-junction transistor.

As mentioned the early germanium transistors were of the grown-junction type. The disadvantage of this type of transistor is that it is not particularly suitable for operations at high frequencies. In addition, it is quite temperature sensitive and can become quite unstable at higher temperatures.

ALLOY-JUNCTION TRANSISTORS

The alloy-junction transistor is made from a rectangular piece of

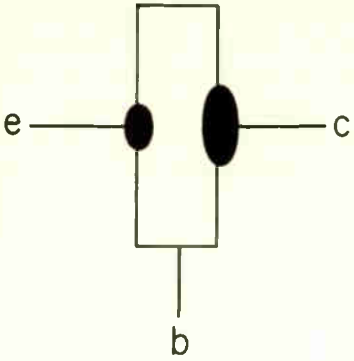


Fig. 26. An alloy-junction transistor.

semiconductor material to which suitable donor materials have been added. This results in an N-type piece of germanium or silicon. Small dots of indium are fused into the opposite sides of the wafer as shown in Fig. 26. The result is that P-type semiconductor material will be formed with the dots fused into the wafer so that we will have a PNP transistor.

An NPN-type alloy-junction transistor may be made by fusing a lead antimony alloy into each of the two opposite sides of a P-type semiconductor wafer. In this type of transistor it is possible to get a more uniform penetration of the lead antimony alloy into the semiconductor material, and this in turn leads to better junction spacing. This will cut down on the width of the space between the emitter and collector and give improved high-frequency performance. In addition, since the mobility of the electrons is more than twice that of holes, the NPN transistor will be better at high frequencies.

The general advantage of the alloy-type junction over the grown-type junction transistors is that they are usable at a somewhat higher frequency. In addition, they have a higher current gain, and the current gain remains stable as the temperature increases.

Surface-Barrier Transistor.

The surface-barrier transistor is similar to the alloy-type transistor except that depressions are etched into the N-type wafer. This permits smaller emitter and collector contacts and results in lower capacities between sections of the transistor which in turn results in better high-frequency performance.

In Fig. 27 we have shown a simplified sketch of a surface-barrier transistor. The sketch in Fig. 27B shows the carrier movement from the emitter across the base to the collector. Notice that in the sketch the emitter is shown smaller than the collector, we have shown it this way because this is the way the semiconductor is actually manufactured.

Various manufacturing techniques are used in the manufacture of the surface-barrier transistor. Both silicon and germanium types are made. In the manufacturing process different materials are evaporated or plated on to the etched depressions depending on the type of tran-

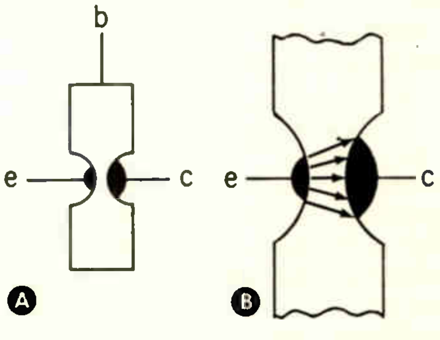


Fig. 27. Sketch of a surface barrier transistor is shown at A. Hole movement across the base is shown at B.

sistor being manufactured. However, regardless of the manufacturing technique used, which is of no interest to the technician, the surface-barrier transistors all have the characteristic of giving good performance at high frequencies.

DIFFUSION TRANSISTORS

To understand diffusion you have to understand a little about the molecular structure of materials. If you look at the wall of a glass jar, to the eye it appears solid with no space between the various molecules making up the jar. However, if you were to fill the jar with hydrogen and store it for any length of time, you would find that in a short while, the jar was no longer filled with hydrogen only, but contained a mixture of hydrogen and air. The reason is that the small hydrogen atoms are able to diffuse or pass right through the spaces between the molecules in the glass. At the same time, molecules of air will diffuse through the glass and pass on into the inside of the bottle. The hydrogen molecule is smaller than the air molecule; therefore the hydrogen will diffuse out of the jar faster than the air will diffuse in.

Diffusion can be used to add impurities to either silicon or germanium, and produce either N-type or P-type semiconductor material. The process can be controlled to provide either very uniform base, emitter, and collector regions, or it can be controlled to provide non-uniform base, emitter, and collector regions.

The Drift Type.

One of the most important uses of the diffusion technique is in the manufacture of transistors with a non-uniform base region. If the emitter and collector junctions are made by the alloy technique, but the base region is made by the diffusion technique and the impurities in the base region varied, we have what is known as a drift transistor. In a typical PNP-drift transistor, accepter impurities are added in the emitter and collector region. These impurities are controlled so that their concentration is uniform throughout the emitter and collector region. At the same time donor impurities are added to the base region. Their concentration is controlled so that it is highest in the region of the emitter-base junction and then drops off quickly and finally reaches a constant value which it maintains over to the base-collector junction, as shown in Fig. 28. This type of transistor is called a drift transistor, and its most important characteristic is its excellent performance at high frequencies. However, notice that it is still a PNP transistor and the basic theory of its operation is similar to that of any other PNP transistor. The improved performance is obtained by varying the concentration of donor impurities in the base region.

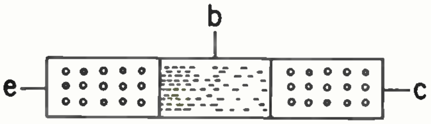


Fig. 28. Diagram showing how a large number of donor impurities increases the electron concentration in the base.

The Mesa Type.

It is also possible to manufacture a transistor using the diffusion technique entirely. An example of this type is the mesa transistor.

In this type of transistor a semiconductor wafer is etched down in steps so that the base and emitter regions appear as plateaus above the collector region as shown in Fig. 29. The advantages of the mesa transistor are good high-frequency performance and very good consistency. By this we mean that it is possible to control the manufacturing techniques quite closely so that the characteristics of mesa transistors of the same type number will be quite similar. This is not necessarily true of other transistors; often their characteristics vary over a wide range.

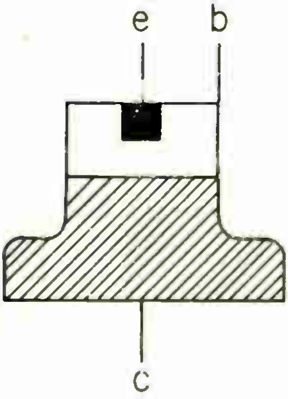


Fig. 29. A mesa transistor.

The Planar Type.

Another type of transistor manufactured by the diffusion technique is the planar type of diffused transistor. This type of transistor is shown in Fig. 30. Notice that each of the junctions is brought back to a common plane, whereas in the mesa type the various junctions are built up in plateaus. The importance of the planar-type transistor is that the junctions can be formed beneath a protective layer. As a result, many of the problems associated with other types of transistors having junctions exposed at the surface are avoided in this type of construction. Important characteristics of the planar transistor are generally very low reverse current and improved dc gain at low-current levels.

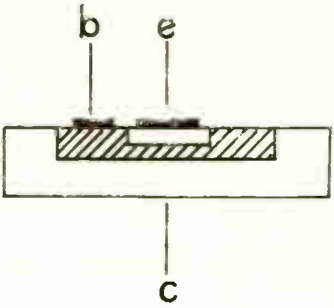


Fig. 30. A diffused planar-type transistor.

EPITAXIAL TRANSISTORS

One of the disadvantages of the diffusion-type transistor is the relatively high resistance of the collector region. This results in slow switching time; it limits the usefulness of the transistor in high-frequency applications. Reducing the resistance of the collector region reduces the collector breakdown voltage and this in turn again reduces the usefulness of the transistor. These problems can be overcome by the epitaxial technique. In this technique a thin high-resistance layer is produced in the collector region and the remainder of the collector region is controlled to keep its resistance low. This results in a transistor that looks something like the one shown in Fig. 31. The primary advantage of this transistor is that it provides good performance at very high frequencies. This technique can be combined with other techniques to produce transistors having varying characteristics. The epitaxial transistor can be referred to as a double-diffused epitaxial transistor. The thin high-resistance collector region is formed by the epitaxial technique and the base and the emitter are formed by the diffusion process - hence the term double diffusion.

All the transistors that we have discussed so far in this section of the lesson are either NPN or PNP transistors. The manufacturing techniques used to manufacture these transistors result in transistors of different characteristics, but the basic theory of operation of these transistors is the same. Now, we'll look at another semiconductor device which operates on a somewhat different principle.

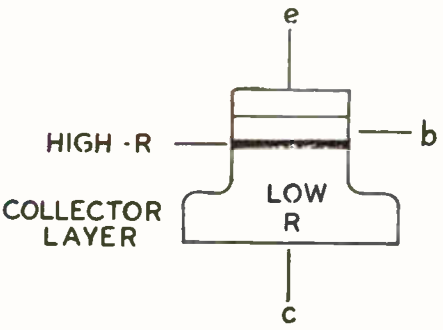


Fig. 31. A double-diffused epitaxial transistor.

THE JUNCTION FIELD-EFFECT TRANSISTOR

An interesting transistor that resembles a vacuum tube very closely in its characteristics and to some extent its operation is a field-effect transistor. One type of field-effect transistor can be made by taking a piece of N-type material as shown in Fig. 32. If the negative terminal of a battery is connected to one end of the material and the positive side of the terminal to the other end, electrons will flow through the material as shown. If we attach a piece of P-type material to one side so that the PN junction is formed and then place a negative voltage on the P-type material as shown in Fig. 32, there will be no current flow across the junction, because the battery biases the junction in such a way that electrons cannot flow from the N-type material to the P-type material nor can holes flow from the P-type material to the N-type.

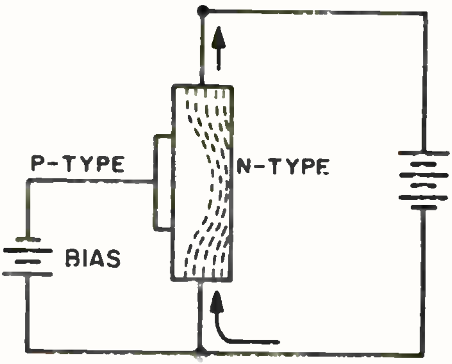


Fig. 32. Drawing showing the basic operation of a field-effect transistor.

However, the negative voltage applied to the P-type material sets up a field in the N-type material. This field opposes the electrons flowing through the N-type material and forces them to move over to one side so that the electron movement follows the path shown in Fig. 32. The negative voltage applied to the P-type material has the effect of increasing the resistance of the N-type material in the area in which the field is affected. It forms a depletion layer around the junction so there will be no free electrons in the N-type material near the junction. If the negative bias voltage is made high enough, it is able to prevent

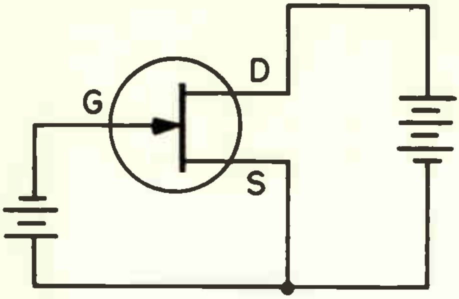


Fig. 33. Schematic representation of the circuit shown in Fig. 32.

the flow of electrons through the N-type material entirely so that the current flow will be cut off. We call this voltage where the bias voltage is high enough to stop the flow of current through the N-type material the "pinch-off" voltage. The N-type material is referred to as a channel, and the P-type material as a gate. This type of transistor is called a "junction field-effect transistor."

The schematic representation of the circuit shown in Fig. 32 is shown in Fig. 33. Notice that the end of the N-type channel at which the electrons from the battery enter is called the "source". The other end, the end from which the electrons leave and flow to the positive terminal of the battery, is called the "drain". The P-type material is called the gate, as we mentioned previously. The transistor is called a field-effect transistor because it is the field produced by the bias voltage applied to the gate that controls the flow of current through the channel. This particular type of transistor is called a junction transistor because a junction is formed between the P and N-type materials. It is called an N-channel transistor because the material in the channel through which current flows has been treated in such a way as to produce an N-type semiconductor material. Thus the complete name for this type of transistor is an N-channel, junction-gate, field-effect transistor. We usually abbreviate field-effect transistor FET, so you will see that this type of transistor is abbreviated JFET to indicate it is a junction-gate type.

An amplifier using a field-effect transistor of this type is shown in Fig. 34. In this circuit we have eliminated the bias battery by means of a resistor connected between the negative terminal of the battery and the source. This resistor might be compared to the cathode-bias re-

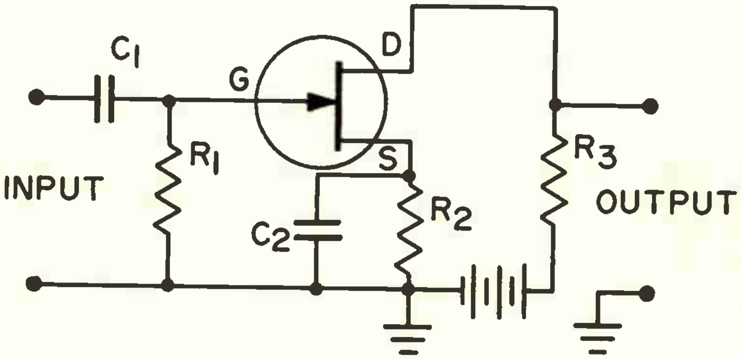


Fig. 34. An amplifier using an N-channel junction gate FET.

sistor in a triode vacuum tube amplifier stage. In the amplifier circuit, electrons flow from the negative terminal of the battery through the resistor R_2 to the source. In so doing they set up a voltage drop across R_2 having a polarity such that the source is positive with respect to ground. Since the gate connects back to ground through R_1, the gate will be at ground potential and this will make the source positive with respect to the gate, or in other words, the gate negative with respect to the source. Therefore none of the electrons in the N channel will flow to the gate, because the gate is negative.

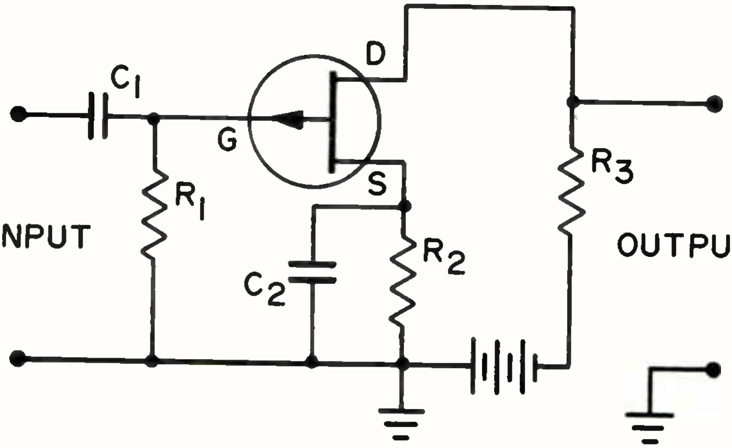


Fig. 35. An amplifier using a P-channel junction gate FET.

Electrons will flow through the N channel to the drain and then through the load resistor R_3 back to the positive terminal of the battery. As the input voltage applied across the input terminals causes the voltage between the gate and the source to vary, the current flow from the source to the drain will vary because the controlling action of the gate on the current through the channel depends upon the voltage between the gate and the source. Thus we have a varying current, which will vary as the input signal varies, flowing from the source to the drain of the transistor and through the load resistor R_3. This varying current flowing through R_3 will produce an amplified signal voltage across R_3.

It is interesting to note the similarity between the circuit shown in Fig. 34 and a triode amplifier. When the input signal swings the gate in a positive direction, current flowing through the transistor will increase; this will cause the voltage drop across R_3 to increase and therefore the voltage between the drain and ground will decrease. Thus a positive-going signal applied to the gate will cause a negative-going signal at the drain. In other words, this transistor inverts the signal phase just as the triode vacuum tube amplifier stage does.

P-Channel JFET.

It is possible to make a P-channel junction-gate field-effect transistor by using a P-type material between the source and drain. The gate is then made of an N-type material. The bias polarity is reversed so that once again the PN junction is biased and no current flows across the junction.

A schematic diagram of an amplifier using a P-channel junction-gate effect is shown in Fig. 35. Notice the schematic symbol for the P-channel unit: we have turned the direction of the arrow around just as we did to distinguish between NPN and PNP transistors. Also notice that in this circuit the battery polarity is reversed. This is because the carriers in the channel in the P-channel unit will be holes. The positive terminal of the battery which connects to the source through R_2 repels the holes and they travel through the channel to the drain where they are attracted by the negative potential connected to the drain. Meanwhile, holes arriving at the drain terminal are filled by electrons which flow from the negative terminal of the battery through R_3 to the drain. At the same time, the positive terminal of the battery attracts electrons from the source creating new holes. These electrons flow from the source through R_2 to the positive terminal of the battery.

The operation of the P-channel, junction-gate effect is the same as with the N-channel unit, except that in one case the majority carriers are electrons, and in the other case they are holes.

In discussing the action of the junction-gate field-effect transistor, we often refer to the reverse bias across the junction creating a depletion layer in the conducting channel. In the case of an N-channel unit, the negative voltage on the P-type gate will repel electrons at the junction so that the electrons have been depleted from that area around the junction. The higher the negative voltage the further the electrons are depleted in the area around the junction, and as we pointed out previously if the voltage is made high enough, all of the electrons will be depleted so that there will be no current flow through the channel. The transistor is referred to as a depletion-type transistor because the bias depletes the number of majority carriers from the channel around the junction region. Remember what we mean by a depletion type of FET; you'll see later there is another type.

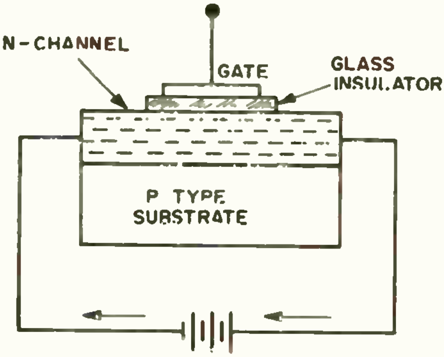


Fig. 36. Current flow through an insulated-gate, N-channel field-effect transistor with no bias applied.

INSULATED-GATE FIELD-EFFECT TRANSISTORS

The transistors we have been discussing so far are called junction-gate field-effect transistors. There is another type of field-effect transistor that is called an insulated-gate field-effect transistor. We usually abbreviate this IGFET.

In the insulated-gate field-effect transistor, the gate is completely insulated from the channel by a thin insulating material. For example, a very thin piece of glass might be placed between the conducting channel and the gate. Thus there is no actual junction formed between the semiconductor materials in the channel and the gate. In an N-channel, insulated-gate field-effect transistor, construction such as shown in Fig. 36 is often used. Here we have an N channel between the source and drain. The substrate on which the channel material is mounted is P-type material and the gate is placed along the channel as shown in the figure. The thin layer of glass prevents any actual contact between the channel and the gate.

In operation, the source and the substrate are connected to the negative terminal of the battery and the drain is connected to the positive terminal. This will permit current to flow from the negative terminal of the battery to the source, through the channel to the drain and then back to the positive terminal of the battery.

When a negative voltage is applied to the gate, it has the effect of repelling electrons away from the gate as before. In addition, the negative potential applied to the gate attracts holes in the P-type material so that the width of the channel is reduced as shown in Fig. 37. Thus the current flow through the channel is restricted by the narrowing of the channel. In effect, the resistance of the channel is increased. We refer to this type of channel as a depletion channel. The transistor is called an insulated-gate-field-effect transistor and it is also referred to as a depletion type because the flow of current through the transistor is controlled by producing a depletion layer in the channel as in the case of the junction transistors discussed previously.

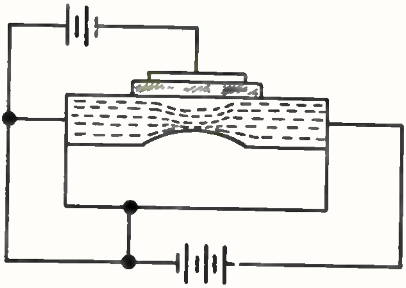


Fig. 37. Current flow through an N-channel IGFET with bias applied.

Both N-channel and P-channel IGFET's are manufactured. The schematic symbols used to represent the two different types are shown in Fig. 38A and B. In A, we have shown the symbol used for an N-channel type, and in B the schematic symbol used for a P-channel type. In operation, the units perform in essentially the same way as the junction-gate units with the exception that there will be no current

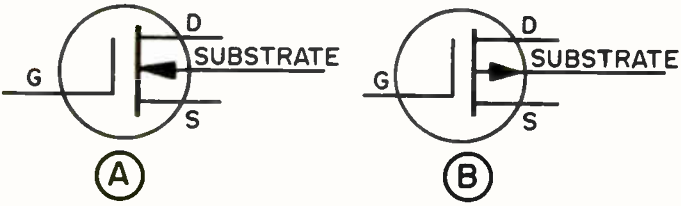


Fig. 38. Insulated-gate field-effect transistors. (A) shows the schematic symbol for an N-channel unit and (B) the symbol for a P-channel unit.

flow at all from the channel to the gate or from the gate to the channel. In the JFET, there may be very small leakage current across the junction. However, a JFET has a high input resistance because this leakage current is low. The IGFET has an even higher input resistance because there is no current flow at all from the gate to the channel or from the channel to the gate. Thus the input resistance of an IGFET is almost infinite.

Enhancement Type.

So far the field-effect transistors we have been discussing are all what are known as depletion types. In the depletion type of FET, the channel is formed and a bias is placed on the gate so as to reduce the size or width of the channel. In the enhancement-type of field-effect transistor, there is no channel present until the bias is applied to the gate. Thus, there is no current flow from the source to the drain through the transistor, unless there is a bias applied to the gate. The polarity of the bias applied to the gate is reversed from what it is in the depletion type, and this bias forms the channel through which current can flow. The operation of the units is the same as with the depletion type with the single exception of the reverse bias. In other words, in the case of an N-channel enhancement-type field-effect transistor, instead of placing a negative bias on the gate to reduce the width of the channel, as we do in the depletion-type transistor, in the enhancement-type we place a positive bias on the gate and produce the N channel.

The enhancement-type field-effect transistor is always an insulated gate type. In the case of a junction FET, if we produced an enhancement type, we would have current flow across the junction because the voltage required to produce the channel would forward bias the junction. However, in the insulated-gate FET, no current can flow across the junction because we have an insulating material between the gate and the channel. Thus we can put any type of bias we want, either forward or reverse bias, on the gate and we still will not get a current flow from the gate to the channel or from the channel to the gate.

The schematic symbol of an N-type IGFET of the enhancement type is shown in Fig. 39A. Notice that we have indicated there is no channel by breaking the channel into three parts. When the correct bias is applied to the gate, an N channel between the source and the drain will be formed. The schematic symbol for the P-channel unit of an enhancement-type IGFET is shown in Fig. 39B.

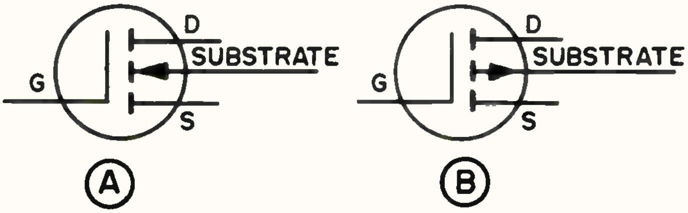


Fig. 39. A shows the schematic symbol for an N-channel enhancement-type IGFET. B shows the P-channel unit.

The operation of the enhancement-type IGFET is basically the same as with the depletion type. It could be used in a circuit similar to the circuits shown in Fig. 34 and Fig. 35.

One of the problems with IGFET's is the very high resistance between the gate and the channel. In shipping these units the manufacturer usually wraps the leads in tin foil to keep them connected together. If he doesn't do this, static charges can build up on the gate because of the very high resistance between the gate and the channel. These static charges may become high enough to actually puncture the insulation between the gate and the channel and thus ruin the unit.

In soldering an IGFET into a circuit, there might be enough leakage from the power line through the tip of your soldering iron to ruin the FET. To prevent this from happening, ground leads should be used on the various connections to the transistor and these leads should be left in place until the transistor is installed in the circuit. Once the transistor is soldered in place, you do not have to be concerned about static charges destroying the unit because the resistance in the circuit will be low enough to prevent static charges from building up to a high enough value to destroy the transistor.

Field-effect transistors are finding their way into commercial equipment, and you should therefore be sure you understand how they operate. You should review the sections on field-effect transistors several times if necessary because you can be sure they are going to be widely used in the future. They offer the advantages of the transistor as well as many of the advantages of the vacuum tube.

THE UNIJUNCTION

Another important semiconductor device is the unijunction. The unijunction is different from a conventional two-junction transistor in that it has only a single junction.

Most unijunctions are made of a bar of N-type silicon. There are two base contacts made to this bar called base 1 and base 2. These contacts are made at the ends of the bar. Between the two bases is a single rectifying contact called the emitter. The schematic symbol of the unijunction is shown in Fig. 40.

In Fig. 41 we have an equivalent circuit showing how the unijunction operates. We have referred to the resistance between base 1 and the emitter as R_{B1} and the resistance between base 2 and the emitter contact as R_{B2}. When a dc voltage is applied to the unijunction between B_1 and B_2, a current will flow through the base as shown. As long as the voltage drop across R_{B1} is greater than the emitter voltage, the emitter will be reverse biased so that there will be no current flow across the junction between the emitter and the base. The voltage across the resistance representing base 1 and the voltage across the resistance representing base 2 will remain constant. The two bases more or less act like two resistors

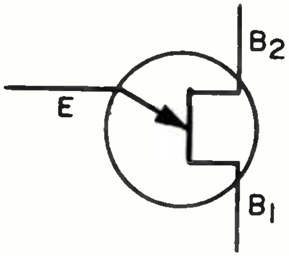


Fig. 40. Schematic symbol of a unijunction.

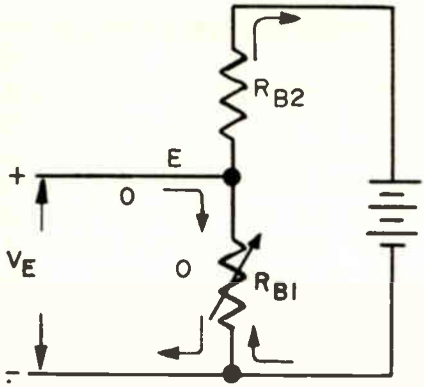


Fig. 41. Equivalent circuit showing the operation of the unijunction.

in series. The positive voltage at the emitter junction prevents any electrons from leaving the base and crossing the junction to the emitter and also prevents holes from traveling from the emitter to the base. There will be a small leakage current across the junction, but this is of no importance insofar as the operation of the unijunction is concerned.

If the voltage, V_E, exceeds the voltage across R_{B1}, then holes will enter the base and flow through R_{B1} as shown by the arrows on the diagram. These holes will cause the number of electrons flowing in R_{B1} to increase. The net result will be that you will have a drop in voltage across R_{B1} but at the same time an increase in current.

You will remember from Ohm's Law that the current flowing in a circuit is equal to the voltage divided by the resistance. If the voltage drops, the current must drop. However, in this device we have a situation where the voltage drops, but the current increases. We refer to this as "negative resistance". Devices that have this characteristic can be used in various types of amplifier circuits.

The unijunctions made for a number of years always made use of an N-type base material and a P-type emitter. However, recently some unijunctions using a P-type base material and an N-type emitter have been developed. The schematic symbol is the same, except that the direction of the arrow is reversed.

Unijunctions have not been widely used in commercial radio and TV equipment; however, they have been used in various pieces of test equipment. It is quite likely that as more transistorized television receivers are manufactured, the unijunction may be used in the sweep circuits since they are quite readily adapted to this type of application.

The important thing for you to remember at this time about the unijunction is that the device has a single junction and that the resistance of the two bases remains essentially constant until the emitter voltage exceeds the voltage across base 1. Then the voltage drop across base 1 decreases while the current flow through it increases, resulting in the negative resistance characteristic of base 1.

SUMMARY

There are too many details in this section to try to summarize them. The important thing for you to do is to realize that the different names assigned to the conventional two-junction transistors indicate the manufacturing process used to make the transistor. Typical two-junction transistors are either NPN or PNP transistors, and the basic theory of operation of the two-junction transistors is the same regardless of the manufacturing technique used. Different manufacturing techniques result in transistors with different characteristics, but the theory of operation is the same.

The field-effect transistor is a transistor that very closely resembles a vacuum tube in many of its characteristics. Remember that there are two basic types: the junction field-effect transistor and the insulated-gate field-effect transistor. In the insulated-gate type, the gate is insulated so that the leakage current to and from the gate is practically zero. This type of transistor has a very high input resistance.

You should also remember that field-effect transistors can be made in both N-channel types and P-channel types. You'll recall that by depletion type we are referring to a transistor where a channel is present. The input voltage to this type of transistor controls its channel width. JFET transistors are all of the depletion type. The IGFET may be either the depletion type or the enhancement type.

The unijunction is a semiconductor device with a single junction. Its use in commercial equipment is somewhat limited at this time, but you should understand the basic fundamentals of the device because it is quite likely that it will be used in the future.

One important point about all types of transistors that we must emphasize is that they are all easily damaged by excessive heat. This is true particularly of germanium transistors, but silicon transistors can also be destroyed by excessive heat. Whenever you have to replace a transistor in a circuit, you should make sure that the point at which you have to solder the transistor in the circuit is clean so that the solder will melt and flow over the connection quickly. Also make sure that the transistor leads are clean. It is a good idea to use a heat sink between the point at which you are soldering and the semiconductor device. A good heat sink is a pair of longnose pliers; simply hold the lead securely in the jaws of the pliers while you are soldering the lead in place. Much of the heat developed at the joint will flow through the pliers and keep the semiconductor device itself from becoming excessively hot. The joint should be soldered as quickly as possible; get the iron off the joint just as soon as the solder has melted and flowed smoothly over the connection.

Semiconductor devices can be damaged by storing them in excessively warm places. Again, this is particularly true of germanium transistors which are more heat sensitive than silicon transistors. Storing semiconductor devices at room temperature will prevent this type of damage. You should avoid storing them in any place where they can become excessively hot.

Now to check yourself on this important section you should answer the following self-test questions.

SELF-TEST QUESTIONS

(aw) Into what two basic types can the grown-junction transistor be divided?

(ax) What type of transistor can the surface-barrier transistor be classified as?

(ay) What is the most important characteristic of the surface-barrier transistor?

(az) What do we mean by a diffussion transistor?

(ba) What is an important use of the diffusion technique in manufacturing transistors?

(bb) What is the difference between a junction-gate field-effect transistor and an insulated-gate field-effect transistor?

(bc) What is a depletion-type field-effect transistor?

(bd) What is an enhancement-type FET?

(be) What is a unijunction?

Answers to Self-Test Questions

(a) Four.

(b) Germanium and silicon.

(c) A covalent bond is the sharing of two electrons by two atoms, one from each atom.

(d) Four. A single atom of germanium or silicon will share an electron from its outer ring and an electron from the outer ring of a nearby atom to form a covalent bond. It will do this with four electrons to establish four covalent bonds.

(e) Intrinsic conduction is conduction due to the formation of hole-electron pairs throughout a germanium or silicon crystal.

(f) No.

(g) Germanium.

(h) Heat.

(i) Silicon.

(j) An N-type material is a material that has been doped so that electrons are the majority carriers. This is brought about by using an impurity that has five electrons in the valence ring so that when it forms covalent bonds with nearby germanium or silicon atoms there will be an electron left over.

(k) A donor material is an impurity which when added to silicon or germanium will form covalent bonds with four nearby atoms and have an electron left over. When a donor material is added to germanium or silicon, N-type material is formed.

(l) Arsenic, antimony, and phosphorous.

(m) P-type semiconductor material is a material that has been doped with an impurity having three electrons in the valence ring. This will leave a covalent bond that is short one electron so there will be a hole in the bond. The hole is in effect a positive charge and hence the majority carriers in the P-type material are the holes or positive charges.

(n) An accepter-type impurity is an impurity with three electrons in the valence ring or shell. It is an accepter-type material because it leaves a hole in the covalent bond which can accept an electron.

(o) Indium, boron and aluminum.

(p) Electrons are the majority carriers in N-type material.

(q) Holes.

(r) When the arsenic loses an electron it will be short one electron to completely neutralize the charge on the nucleus, and therefore the atom will have a positive charge. Meanwhile the atom of silicon or germanium that has received the extra electron will have a negative charge on it.

(s) There is no charge on the crystal, it is neutral. Although some regions may have a positive charge, other regions may have a negative charge; the crystal itself neither gains nor loses electrons and therefore it does not have any charge.

(t) Holes are produced.

(u) Diffusion is a random motion of the carriers in a semiconductor material. It goes on at all times in the crystal and every effort is made to keep diffusion as low as possible since it contributes nothing insofar as the usefulness of the material in semiconductor devices is concerned.

(v) Drift.

(w) Electrons are the majority carriers in an N-type material and they move from the end to which the negative potential is applied towards the end to which the positive potential is applied.

(x) Holes are the majority carriers in a P-type material and they move from the end to which the positive potential is applied to the end to which the negative potential is applied.

(y) No - the crystal will remain electrically neutral. In the case of N-type material, exactly the same number of electrons will leave the positive end of the crystal and enter the negative end of the crystal. In the case of the P-type material, electrons will leave the end to which the positive potential is connected creating holes. Exactly the same number of electrons will enter the end to which the negative potential is connected to fill holes arriving at the negative end.

(z) No. For a given potential and given size of crystal, electrons will move at approximately twice the rate through an N-type crystal as the holes will through a P-type crystal.

(aa) The N-type material will have the lower resistance. This is due to the higher mobility of the electrons in the N-type material than the holes in the P-type material.

(ab) Detectors and rectifiers.

(ac) The depletion layer is an area on both sides of the junction. On the P-side of the junction there is a shortage of holes and on the N-side of the junction there is a shortage of electrons. The shortage is caused by a few of the majority carriers crossing the junction in each way building up a charge at the junction so that the majority carriers are repelled away from the junction.

(ad) The potential barrier is the voltage built up across the junction by the diffusion of majority carriers across the junction. The holes that diffuse across the junction into the N-side of the junction create an area that has a negative charge in the P-side of the junction. Similarly, the electrons diffusing across the junction into the P-side create an area on the N-side of the junction that has a positive charge. This charge across the junction eventually becomes high enough to prevent any further diffusion of holes and electrons across the junction.

(ae) No. The net charge on the crystal will remain zero. There may be areas on the crystal that have a positive charge, and other areas that have a negative charge, but since the crystal itself neither gains nor loses electrons, the net charge on the crystal will remain zero.

(af) Yes. Minority carriers crossing the junction tend to weaken the potential barrier established across the junction by majority carriers diffusing across the junction. When the potential barrier is weakened, additional majority carriers can cross the junction. Thus we end up with carriers crossing the junction in both directions. This adds nothing to the useful current that the diode can handle, but it does contribute to heating and thus limits the useful current that can cross the junction.

(ag) When a junction is forward biased we have a positive potential applied to the P-side and a negative potential applied to the N-side. This permits electrons to freely cross the junction from the N region to the P region. Similarly holes can cross the junction from the P region to the N region.

(ah) When a junction is reverse biased we have a negative potential connected to the P region and a positive potential connected to the N region. The positive potential connected to the N region repels holes in the P region away from the junction so that they cannot cross the junction. Similarly, the negative potential applied to the P region repels electrons in the N region away from the junction so that they cannot cross the junction. When a junction is reverse biased, majority carriers normally cannot cross the junction.

(ai) When there is no voltage applied to a semiconductor diode, the net current flow across the junction is zero. However, in the case of a vacuum tube where there is no voltage applied between plate and cathode, some electrons will leave the cathode with sufficient energy to travel over to the plate. As a result, there will be a small current through the tube even though there is no voltage applied between the plate and cathode.

(aj) When a semiconductor diode is reverse biased, there will be a small current flow across the junction due to minority carriers. As long as the breakdown voltage of the diode is not exceeded, this current will be quite small. In the case of a vacuum tube, when the plate is made negative with respect to the cathode, the plate will repel electrons so that there will be no current flow through the vacuum tube.

(ak) A Zener diode is a diode used in applications where a reverse bias is placed across the junction. The diode is designed to break down at a certain voltage and then maintain a constant voltage. If the voltage tries to increase above this constant value, the current flow through the Zener diode will increase so that the diode can be used in voltage regulating circuits and also can be used as a voltage reference source.

(al) A tunnel diode is a diode where the electrons cross the junction by a process similar to tunneling across the junction. The tunnel diode has a characteristic of introducing negative resistance into the circuit when a certain voltage is applied across the junction. In other words, when the voltage across the diode increases, the current flow through the diode decreases. Similarly, when the voltage decreases the current increases. Because of this negative resistance characteristic, the tunnel diode can be used as an oscillator.

(am) A p-i-n diode is a diode that is primarily used as a variable resistance. The resistance of the diode varies as the voltage across it is varied. The p-i-n diode is used in automatic gain control circuits to vary the strength of the signal reaching amplifier stages.

(an) The base region is the center region of the transistor. On one side of the base region is the emitter, and on the other side is the collector.

(ao) Germanium and silicon.

(ap) PNP transistors and NPN transistors.

(aq) Forward bias.

(ar) Reverse bias.

(as) The base region is usually comparatively thin.

(at) See Fig. 22.

(au) See Fig. 24.

(av) Holes are useful current carriers in a PNP transistor.

(aw) NPN and PNP transistors.

(ax) An alloy-type transistor.

(ay) Good high-frequency performance.

(az) A diffusion transistor is a transistor which has been made by diffusing the impurities into the emitter, base and collector regions.

(ba) One of the most important uses of the diffusion technique is in the manufacture of non-uniform base regions.

(bb) In a junction-gate field-effect transistor there is an actual contact between the channel material and the gate. There will be some current flow across the contact at all times due to minority carriers crossing the junction. In addition, if the junction is forward biased there will be a high current flow across the junction. In an insulated-gate field-effect transistor a glass or similar insulating material is used between the material in the channel and the gate. Since there is an insulator between the gate and the channel, there will be little or no current flow across the insulator either due to minority carriers when there is a reverse bias applied, or due to majority carriers with a forward bias applied.

(bc) A depletion-type FET is a unit in which the channel is present at all times. The transistor works by depleting or reducing the size of the channel.

(bd) An enhancement FET is a unit in which there is no channel present until the operating bias is applied between the gate and the material in which the channel is formed.

(be) A unijunction is a semiconductor device having two base connections but only a single junction. The junction is called the emitter. The single junction makes the unijunction quite different from the conventional two-junction transistor.

Lesson Questions

Be sure to number your Answer Sheet B112.

Place your Student Number on every Answer Sheet.

Most students want to know their grades as soon as possible, so they mail in their answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable. However, don't hold your answers too long; you may lose them. Don't hold answers to more than two sets of lessons at any time, or you may run out of lessons before new ones can reach you.

1. Name the two most important semiconductor materials used for transistors.
2. When a donor type of material is added to a silicon or a germanium crystal, what type of semiconductor material is produced? Does this type have free electrons or free holes?
3. What effect do the two layers of ionized atoms at the junction in a PN diode have on the majority carriers in the vicinity of the junction?
4. To which side of a PN junction diode do you connect the positive battery terminal if you wish to place a forward bias on the junction?
5. If a reverse bias is applied to a junction diode, what effect will a small increase in bias have on the current flowing, provided the reverse voltage does not exceed the breakdown voltage?
6. What is a Zener diode?
7. In a PNP transistor, what happens to a hole that crosses the emitter and the base and moves into the collector?
8. What is a drift transistor?
9. What is an N-channel, junction-type field-effect transistor?
10. What do we mean when we refer to a field-effect transistor as an enhancement type?

CASHING IN ON DISCONTENT

Discontent is a good thing--if it makes you want to do something worthwhile. If you had not been discontented, you would never have enrolled for the NRI course.

Practically everyone is discontented. But some of us are "floored" by discontent. We develop into complainers. We find fault with anything and everything. We end up as sour and dismal failures.

Those of us who are wise use our discontent as fuel for endeavor. We keep striving toward a goal we have set for ourselves. We are happy in our work. We face defeat, and we come out the victors.

At this minute you may be discontented with many things--your progress with your course, your earning ability, yourself.

Make that discontent pay you dividends. Don't let it throw you down. If you do, you may never be able to get up again. Keep striving to remove the cause of your discontent. Remember that it's always darkest before the dawn. And a real NRI man works hardest and accomplishes most when he is face to face with the greatest discouragements.

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STUDY SCHEDULE

☐ **1. Introduction . . . . Pages 1-2**
You learn some of the advantages and disadvantages of transistors compared to vacuum tubes.

☐ **2. Semiconductor Fundamentals . . . . Pages 3-13**
You learn about conductors, insulators and semiconductors. You study important characteristics of germanium and silicon and how they are "doped" for use in transistors.

☐ **3. Current Flow in Semiconductors . . . . Pages 14-18**
You study current flow in N-type and P-type semiconductor material.

☐ **4. Semiconductor Diodes . . . . Pages 18-29**
You learn about current flow in diodes with forward bias and reverse bias. You study several important types of diodes.

☐ **5. Semiconductor Triodes . . . . Pages 30-39**
In this section you study PNP and NPN transistors and how they are biased.

☐ **6. Semiconductor Types . . . . Pages 39-52**
In this section you learn about a number of different types of transistors. You also study field-effect and unijunction transistors.

☐ **7. Answer the Lesson Questions.**

☐ **8. Start Studying the Next Lesson.**

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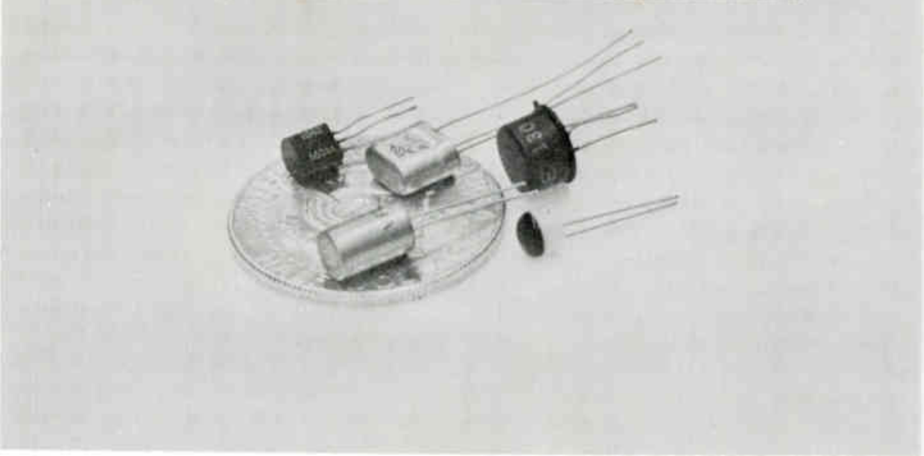
HOW TRANSISTORS WORK



In the preceding lessons you studied tubes, and you saw how they are used in different circuits. In this lesson you will study semiconductor devices - these devices have already replaced tubes in many important applications and are rapidly moving into new areas that were once dominated entirely by tubes.

An example of the importance of semiconductor devices can be seen in entertainment-type equipment. Just a few years ago all the rectifiers used in this equipment were vacuum tubes. Today, however, the vacuum tube is no longer used for this purpose; rectifiers in the modern entertainment-type equipment are all semiconductor devices.

Semiconductor devices used as rectifiers have two elements and are called diodes just as two-element vacuum tubes are called diodes. Semiconductors used to amplify signals usually have three or more elements and are called transistors. There are a large number of different types of transistors available today, but for the most part these transistors can be classified into two types, the NPN transistor and the PNP transistor. If you understand how these two transistor types work, you should have little difficulty understanding how all others work and any new transistors that might be introduced in the future. You will run into many different types of transistors identified by different names, but these names usually refer to the method used in manufacturing the transistor rather than the manner in which it operates.

There are some similarities between tubes and semiconductors. A two-element vacuum tube can be used to change an alternating current to a direct current; a two-element semiconductor can be used for the same purpose. A triode vacuum tube can be used to amplify a signal; a transistor can be used for the same purpose. However, this is where the similarity ends. Most tubes are vacuum devices; in other words, all the air and gas have been evacuated from inside the tube. On the other hand, a semiconductor is a solid device and there is no space between the elements in it. We have a current flow through a vacuum in a tube, but we have a current flow through a solid in a semiconductor.

The importance of semiconductors cannot be overemphasized. They have completely supplanted the vacuum tube in portable radio receivers and in automobile receivers. Almost all high fidelity and stereo' equipment manufactured today uses semiconductors exclusively - the only tube-operated equipment of this type you are likely to encounter is equipment that is several years old. Semiconductors are finding their way into television receivers and it is probably just a matter of time before they completely replace the vacuum tube.

Semiconductors have several advantages over the vacuum tube. Perhaps one of the most important advantages is that they do not require any heater or filament power. Not only is this a power saving in the operation of the equipment, but it also removes considerable heat from the equipment. Heat is probably the thing that causes the most damage to parts in electronic equipment. Thus with the removal of the heater or filament power from the equipment, other components such as capacitors, etc. will last longer.

Semiconductors are very rugged. They are solid devices and hence not subject to breakage from mechanical shock as tubes are. An important advantage of transistors is that they will operate on a comparatively low voltage, and this usually results in some reduction of the power required in the equipment.

Although semiconductors have many advantages over vacuum tubes, they do have some disadvantages. One disadvantage is that it is usually not possible to get as high a gain in an amplifier stage using a transistor as it is in a similar stage using a tube. Therefore to get the equivalent gain, more transistor stages are required than vacuum-tube stages. Another disadvantage of the transistor is that its characteristics are not as constant as those of a vacuum tube. In other words, you are more likely to run into difficulty replacing a transistor than you are in replacing a tube because the replacement transistor's characteristics might be considerably different from the characteristics of the original transistor. Another disadvantage of both diode semiconductors and transistors is that their characteristics can vary appreciably with changes in temperature. As a matter of fact, some semiconductor devices are easily destroyed by too much heat.

In spite of the fact that semiconductor devices have some disadvantages when compared to vacuum tubes, their advantages more than outweigh the disadvantages and their importance in the field of electronics is continually growing. Therefore it is important that the technician have a good understanding of semiconductor fundamentals, how they are used, and how they operate. Before going ahead to see how semiconductors are used as rectifiers and amplifiers, we need to know more about certain types of atoms, in order to understand how these devices work.

Semiconductor Fundamentals

You have already learned that certain materials will conduct electricity readily and that some materials will hardly pass any electric current at all. The materials that will conduct current readily are called conductors and those that will not conduct current are called insulators. Midway between the two types of materials is a group of materials called semiconductors. These materials are not good conductors, nor are they particularly good insulators. Two examples of semiconductor materials are germanium and silicon. These are the materials that we will be mostly concerned with in this section. Both diode semiconductors and transistors are made from germanium and silicon. A new material that shows promise for use in semiconductors is gallium arsenide. It's likely that this material will be used in semiconductors in the future. Before going ahead with our detailed study of semiconductor materials, let us review a few important facts about conductors and insulators.

CONDUCTORS AND INSULATORS

You will remember that all materials are made up of atoms. An atom is the smallest particle of a material that retains the characteristics of the material.

In the center of the atom is the nucleus. This nucleus contains a positive charge. The number of positive charges on the nucleus distinguishes one material from another. In other words, the nucleus of a copper atom does not have the same number of positive charges as the nucleus of an iron atom.

Each atom normally has enough electrons, which have a negative charge, to exactly neutralize the positive charge on the nucleus. Thus, the hydrogen atom which has a nucleus with one positive charge will have one electron, and the helium atom which has a positive charge of two in the nucleus will have two electrons. Another atom that has a nucleus with 30 positive charges will have 30 electrons to exactly neutralize the positive charge on the nucleus.

The electrons in an atom arrange themselves in shells around the nucleus. The total number of electrons will normally be just enough to neutralize the charge on the nucleus. However, there is a maximum number of electrons that can be forced into each shell. In the first shell around the nucleus, the maximum number of electrons is 2. In the second shell, the maximum number of electrons is 8, and in the next shell the maximum number of electrons is 18. A shell can have less than the maximum number of electrons, but not more than the maximum number.

Conductors.

An example of an atom in a conductor is shown in Fig. 1. We have drawn the shells in the form of rings, but remember that this atom actually has three dimensions, not two. Notice that in this atom there are two electrons in the first shell,

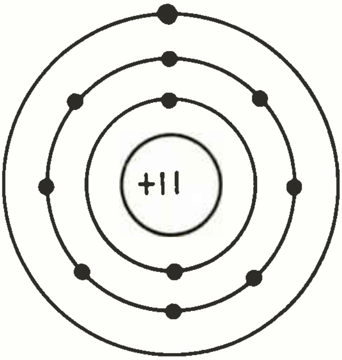


Fig. 1. An atom of a conductor.

8 electrons in the next shell and only one electron in the third shell. The outer shell is called a valence shell. The single electron in the third shell, which is called the valence electron, is not very closely bound to the nucleus; it can easily be removed from the atom. Thus a material of this type has a large number of electrons that can easily be removed from their atoms. When these electrons are forced to move in one direction we have a current flow. Thus a material that has only one or two electrons in an outer shell that could have many more, is a conductor, because the one or two electrons in the outer shell are not closely bound to the nucleus.

Insulators.

An atom of an insulator is shown in Fig. 2. Notice that in this atom there are two electrons in the first shell, and 8 electrons in the second shell. Both the shells are completely filled and will be closely bound to the nucleus. This means that it is very difficult to get one of these electrons out of an atom and therefore this material is an insulator or nonconductor.

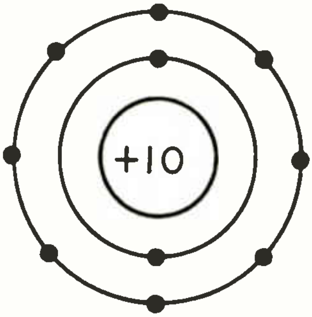


Fig. 2. An atom of an insulator.

Remember the important difference between conductors and insulators. A conductor is a material that has one or two electrons in the outer shell that are not closely bound to the nucleus, whereas an insulator is a material in which the outer shell of each atom is filled or almost filled so that the electrons are closely bound to the atom and cannot be easily removed. Because these electrons cannot be removed from the atom, this type of material normally will not conduct current, and hence is called an insulator.

SEMICONDUCTOR MATERIAL

A material that is classified as a semiconductor has electrical characteristics midway between those of a conductor and those of an insulator. The electrons in a semiconductor can be removed from their atoms when some type of external energy, such as voltage, heat, or light is applied to the material. Then the material acts like a conductor.

The most important semiconductor materials used for transistors are germanium and silicon. The first low-cost transistors were germanium transistors, but recent developments have lowered the cost of silicon transistors so that most of the new transistor types being introduced are silicon. Both germanium and silicon are very abundant elements, but neither is found in the pure state, and it is quite difficult to process them to the high state of purity required for use in transistors. The first transistors were made of germanium because techniques for getting pure germanium were developed first. However, now it is possible to refine silicon to the high degree of purity required, at a reasonable cost, and since silicon has several advantages over germanium for use in semiconductor devices it has in many ways replaced germanium.

In general, there is not too much difference between the operation of semiconductor devices made from germanium and those made from silicon. We will cover the important points of these devices made from both materials since you will run into semiconductor devices of both types.

The Germanium Atom.

The arrangement of electrons about the nucleus in a germanium atom is shown in Fig. 3A. The nucleus of the germanium atom has a positive charge of 32. Thus as you might expect, there will be 32 electrons revolving in the shells about the nucleus. There are two electrons in the first shell, eight in the second, eighteen in the third and four in the fourth shell. Thus, the first, second and third shells are filled, but there are only four electrons in the outer shell. However, these four electrons, which are called the valence electrons, are bound to the nucleus much more so than the one or two electrons found in the outer shell of a conductor.

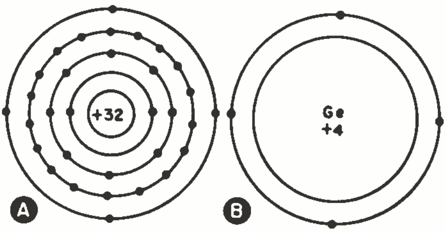


Fig. 3. (A) is the germanium atom with a charge of 32. (B) shows the simplified symbol.

The important electrons in the germanium atom, insofar as its use in semiconductors is concerned, are the four electrons in the outer shell because the shell is not filled. The other electrons are bound so closely to the nucleus that they cannot easily be removed. Therefore, germanium is often represented as shown in Fig. 3B.

The Silicon Atom.

The arrangement of electrons about the nucleus in a silicon atom is shown in Fig. 4A. The nucleus of the silicon atom has a positive charge of 14. Therefore, there will be fourteen electrons revolving about the nucleus. There are two electrons in the first ring, eight in the second and four in the third. Thus the first and second rings are filled, but there are only four electrons in the outer shell. These four

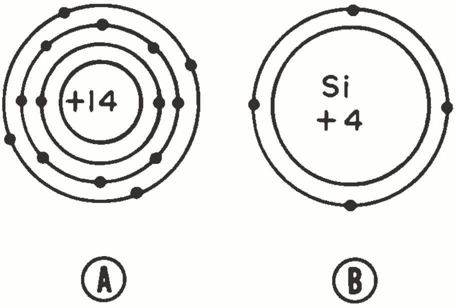


Fig. 4. (A) shows the silicon atom with a charge of 14. (B) shows the outer shell with four electrons.

electrons are the valence electrons like the four in the germanium atom and are bound fairly closely to the nucleus. As in the case of the germanium atom, the four electrons in the outer ring are the ones that are of importance in the use of silicon in semiconductors.

Notice the similarity between the silicon and germanium atoms. In both atoms, the outer shell or ring has four electrons, and all the other shells are filled.

The tendency of some materials like silicon and germanium, that do not have the outer shell completely filled with electrons, is to get additional electrons to fill up the outer shell. In pure germanium and silicon, the electrons in the outer shell of one atom are bound as closely to that atom as the four electrons in the outer shell of another atom. Therefore one atom cannot pull electrons away from another atom. Instead, two nearby atoms will share one outer electron from each atom. In other words, two atoms of germanium may share electrons as shown in Fig. 5A; and two atoms of silicon may share electrons as shown in Fig. 5B. By sharing electrons in this way, each atom will partly fill its outer shell. This pair of shared electrons, one from each of two atoms, is called "a covalent bond".

In order to try to fill its outer ring with electrons, a single germanium atom or a single silicon atom will establish covalent bonds with four other atoms. This arrangement of atoms in a piece of germanium is shown in Fig. 6A. A similar arrangement of atoms in a piece of silicon is shown in Fig. 6B. These pieces of silicon and germanium are called crystals and the way in which they are arranged is called a lattice structure. Each atom shares each of its four valence electrons with one valence electron of another atom to form these bonds.

INTRINSIC CONDUCTION

Even at comparatively low temperatures, there is heat energy in all materials. This energy is sufficient to cause a few of the electrons to move out of their proper place in the lattice structure of either the germanium crystal or the silicon crystal and become free electrons. These free electrons are available for conduction of electric current. The number of free electrons available is much higher in germanium than it is in silicon.

When one of these electrons moves out of its position in the lattice structure, it leaves an empty space in the crystal lattice. This empty space is called a hole. An electron from a

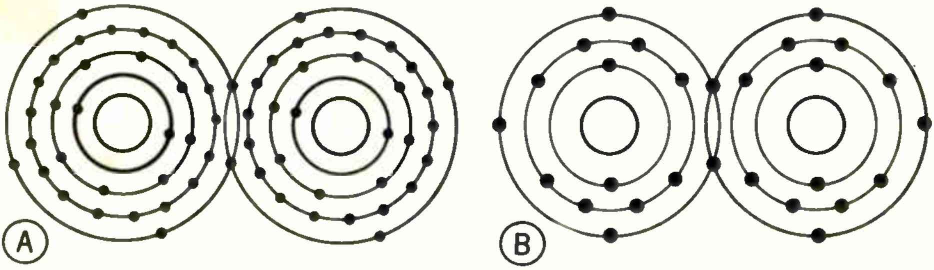


Fig. 5. The sharing of two electrons by two germanium atoms is shown at A; by two silicon atoms at B.

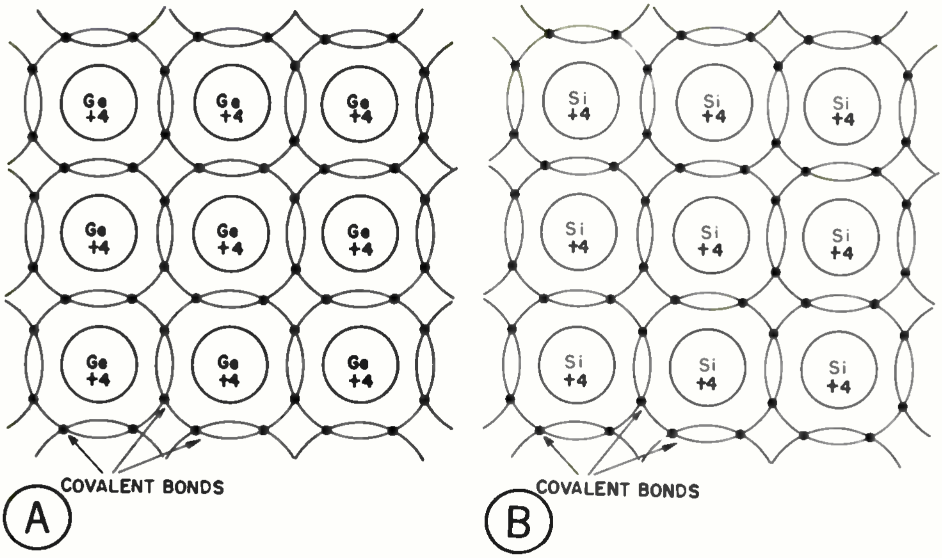


Fig. 6. The lattice structure of germanium is shown at A; of silicon at B.

nearby atom can move into this hole thus creating a new hole at the place it left. Another electron may move out of still another atom to fill this new hole, leaving behind it a hole. This movement of an electron to fill a hole thus creating a new hole in the place it left makes it look as if holes themselves move. Furthermore, since the hole represents a missing electron, it has a positive charge.

In a piece of germanium or silicon, the electrons are in a constant state of motion about their atoms. If in its movement an electron comes closer to a hole than to its own atomic nucleus, it will be strongly attracted to the hole and will leave its atom. When there is no voltage applied across the crystal, the movement of a hole or an electron is a random movement. Holes and electrons may move in any direction.

If heat or some other form of external energy is applied to the crystal, the resistance of the material is reduced. This happens because more electrons are freed by the energy applied to the crystal. In addition, the speed of the random movement is increased.

The movement of an electron out of an atom forms a hole in the atom. Thus, whenever an electron is freed from an atom a hole is formed. This free electron and the hole it forms are called a "hole-electron pair". The formation of hole-electron pairs is a continuous process. Also the filling of holes by electrons is a continuous process. In other words, the process of an electron leaving its atom and forming a hole, and another electron moving in to fill the hole and in so doing creating a new hole, is a continuous process. The conduction of electricity in pure germanium or pure silicon crystals due to the formation of hole-electron pairs is called the intrinsic conduction.

The conductivity of a germanium crystal or a silicon crystal, which is the ability of the material to conduct an electric current, depends on the average length of time an electron is free and on the number of free electrons. We mentioned previously that there are more electrons free if external energy, such as heat, is applied to the material. Therefore the conductivity rises as the temperature of the material is increased.

This type of conduction is much higher in germanium than it is in silicon. As an example, if we had a germanium crystal exactly one centimeter on each side and measured the resistance across two parallel surfaces, we would find the resistance to be approximately 60 ohms. The resistance of an equivalent piece of silicon would be approximately 60,000 ohms. Thus intrinsic conduction is much higher in germanium than it is in silicon.

Intrinsic conduction in transistors is undesirable. It is kept as low as possible by holding the operating temperature of the material down. Transistors are also shielded from light because light is a form of energy and light striking the crystal will increase the intrinsic conduction. Since silicon has a much lower intrinsic conduction than germanium, semiconductors made from silicon are less affected by heat than are semiconductors made from germanium. This is one of the chief advantages of silicon over germanium as a semiconductor material.

In their pure forms, neither germanium nor silicon are useful in semiconductor devices. In fact, in spite of intrinsic conduction, neither material is a good conductor at room temperature; they are both fairly good insulators. To use these materials in semiconductors, controlled amounts of other selected elements called impurities are added to the crystals to alter their characteristics. By adding these materials we can produce two types of silicon and two types of germanium. They are called N-type and P-type. Now, let us study the characteristics of these two types of materials.

N-TYPE MATERIAL

N-type silicon or germanium can be produced by adding as an impurity an element that has five electrons in its outer ring. An example of this type of material is arsenic. Arsenic has a positive charge of 33 on the nucleus and has 33 electrons in the shells surrounding the nucleus. There are two electrons in the first shell, eight in the second, eighteen in the third and five in the fourth or outer shell. In other words, arsenic is just like germanium except that the nucleus has one more positive charge and there is one additional electron in the outer shell.

If a small amount of arsenic is added to the germanium, the arsenic atoms will form covalent bonds with the germanium atoms as shown in Fig. 7. However, to form the covalent bonds with its neighboring germanium atoms, the arsenic atom needs only four of the electrons in its outer shell. Therefore there will be one electron left over when the arsenic atom forms covalent bonds with the four neighboring germanium atoms. This electron is free to move about within the crystal in exactly the same manner as a single valence electron in a good metal conductor. The addition of arsenic, which produces these free electrons, greatly reduces the resistance of the material.

When a small amount of arsenic

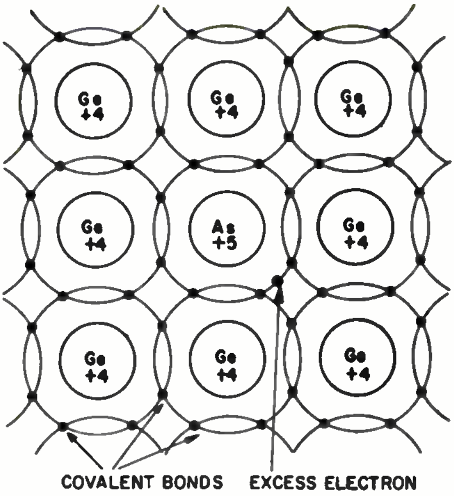


Fig. 7. Germanium with arsenic added.

is added to a silicon crystal exactly the same thing happens. The arsenic atom forms covalent bonds with the silicon atoms. As in the case of the germanium atom, only four of the electrons in the outer shell of the arsenic atom are used in forming these covalent bonds so there will be one electron left over.

When germanium or silicon have had an impurity added to them we say they have been doped. When semiconductor material has been doped with a material such as arsenic that results in there being excess electrons, we call it an N-type material. The N refers to the negative carriers, which are the free electrons. Arsenic is called a donor impurity because it donates an easily freed electron.

In addition to arsenic, other materials have been used as donors. Phosphorus, which has a total of fifteen electrons, can be used. The phosphorus atom has two electrons in the first shell, eight in the second and five in the third. Four of the electrons in the valence shell or ring will form covalent bonds with germanium or silicon atoms leaving a fifth electron free. Antimony, which has 51 electrons, also has been used as a donor. Antimony has two electrons in the first shell, eight in the second, eighteen in the third, eighteen in the fourth and five in the fifth or valence shell.

P-TYPE MATERIAL

If instead of adding a material with five electrons in its valence shell, we add a material with only three electrons in the valence shell, we have a situation where the impurity added to the silicon or germanium has one less electron than it needs to establish covalent bonds with four neighboring atoms. Thus, in one covalent bond there will be only one electron instead of two. This will leave a hole in that covalent bond.

A material that is frequently used for this purpose is indium. Indium has 49 electrons, two in the first shell, eight in the second, eighteen in the third, eighteen in the fourth and three in the fifth or valence shell.

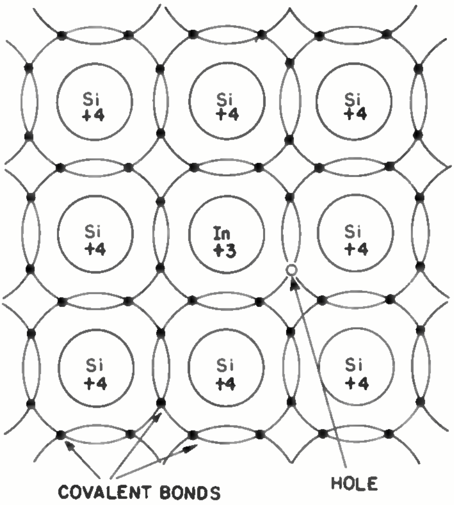


Fig. 8. Silicon with indium added.

The manner in which indium forms covalent bonds with neighboring silicon atoms is shown in Fig. 8. It forms covalent bonds with germanium atoms in the same way.

We mentioned previously that even at comparatively cold temperatures there is some heat energy within the crystal and thus there will be a few free electrons moving about the crystal. These free electrons are strongly attracted to the holes in the covalent bond produced where an indium atom has replaced a silicon or a germanium atom. Thus an electron will move into a hole in the covalent bond producing a new hole in another atom and giving the effect that the hole is moving as shown in Fig. 9.

Since a hole in the crystal actually represents a shortage of an electron, it is an area with a positive charge. Therefore when a semiconductor material has been doped with a material such as indium that produces holes in the lattice structure, we call it a P-type material. P stands for positive; since holes represent a shortage of an electron we say they act as positive carriers. The indium is called an accepter impurity because its atoms leave holes in the crystal structure that are free to accept electrons. In addition to indium, boron and aluminum are also used as accepter impurities. Boron has 5 electrons, two in the first shell and three in the second which is the valence shell. Aluminum has 13 electrons, two in the first shell, eight in the second and three in the third or valence shell.

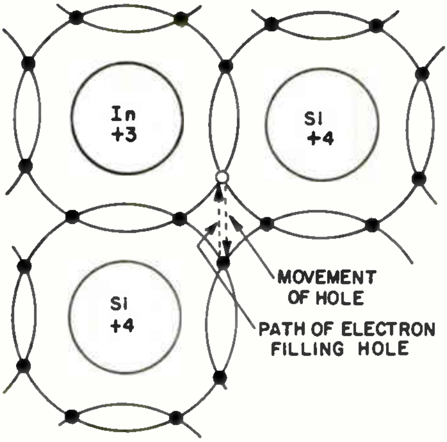


Fig. 9. When an electron fills a hole, another hole will apparently move to where the electron was.

CHARGES IN N-TYPE AND P-TYPE MATERIAL

When a donor material such as arsenic is added to germanium or silicon, the fifth electron in the valence ring of the arsenic atom does not become part of a covalent bond. This extra electron may move away from the arsenic atom to one of the nearby germanium or silicon atoms.

The arsenic atom has a charge of +33 on the nucleus and normally has 33 electrons to neutralize this charge. When the electron moves away from the atom there will be only 32 electrons to neutralize the charge on the nucleus, and as a result there will be a small region of positive charge around the arsenic atom. Similarly, the excess electron that has moved into a nearby germanium or silicon atom will provide an excess electron in the atom. In the case of the germanium atom there will be a total of 33 electrons around a nucleus requiring only 32 electrons to completely neutralize it, and in the case of the silicon atom there will be 15 electrons around the nucleus requiring only 14 electrons to neutralize it. This means that the atom will have an extra electron so that there will be a region of negative charge around this atom.

It is important to notice that although there is a region of positive charge around the arsenic atom after the electron has moved away, and a region of negative charge around the germanium or silicon atom taking up the extra electron, the total charge on the crystal remains the same. In other words, a given crystal will have a net charge of zero. This means that there will be exactly enough electrons to neutralize the positive charges on the nuclei on the various atoms. But because some of the electrons may move about in the crystal, there will be regions in the crystal where there are negative charges and other regions where there are positive charges, even though the net charge on the crystal is zero.

In a P-type material to which material such as indium has been added we will have a similar situation. You will remember that the indium atom has only three electrons in its valence ring. These are all that were needed to neutralize the positive charge on the nucleus. However, with only three electrons in the valence ring, there is a hole in one of the covalent bonds formed between the indium atom and the four adjacent germanium or silicon atoms. If an electron moves in to fill this hole, then there is one more electron in the indium atom than is needed to neutralize the charge on the nucleus. Thus there will be a region of negative charge around the indium atom. Similarly, if one of the germanium or silicon atoms has given up an electron to fill the hole in the covalent bond, then the atom which has given up the electron will be short an electron so that there will be a region of positive charge around this atom. Again, while this giving up of an electron by a germanium atom and the acceptance of an electron by the indium atom ionizes or charges both atoms involved, the net charge on the crystal is still zero. We simply have one atom that is short an electron and another atom that has one too many. The crystal itself does not take on any charge.

These ionized atoms produced in both the N-type and the P-type germanium and the N-type and the P-type silicon are not concentrated in any one part of the crystal, but instead are spread uniformly about the crystal. If any region within the crystal were to have a very large number of positively charged atoms, these atoms would attract free electrons from other parts of the crystal to neutralize part of the charged atom, so that the charge would be spread uniformly about the crystal. Similarly, if a large number of atoms within a small region have had an excess of electrons, these electrons would repel each other and spread throughout the crystal.

Both holes and electrons are involved in conduction at all times. Holes are called positive carriers and electrons negative carriers. The one present in greatest quantity is called the majority carrier; the other is the minority carrier. In an N-type material, electrons are the majority carriers and holes are the minority carriers, whereas in a P-type material, holes are the majority carriers and electrons the minority carriers.

SUMMARY

This is a very important section of this lesson. You have covered many of the fundamentals of semiconductors on which we will build the remainder of the lesson. It is important that you understand the basic theory of semiconductors in order to be able to understand how semiconductor diodes and transistors work. We will summarize the important points that were covered in the preceding section.

If any of these points are not clear, you should go back and study the lesson again until they are clear. If you understand the first section of the lesson, you should be able to understand the material following without too much difficulty. However, if you do not understand what has been covered previously, you will have difficulty understanding what is to follow.

Pure semiconductor material such as germanium or silicon is a very poor conductor. In fact, it is an insulator if it is protected from all outside sources of energy. However, even at room temperature there is enough heat present in germanium and silicon to produce some electron and hole movement. The movement is much greater in germanium than it is in silicon.

An electron movement out of a covalent bond in a germanium or silicon atom leaves a hole in that bond. The hole will attract an electron from a nearby atom, producing a hole in that atom. Thus, both the hole and the electron appear to move. The holes are positive carriers and the electrons negative carriers of electricity. This formation of hole-electron pairs is undesirable in transistors and steps are taken to keep it as low as possible. The formation of hole-electron pairs increases as the temperature increases and is a much more serious problem in germanium-type semiconductor material than in silicon-type semiconductor material.

Semiconductor materials can be doped by adding small amounts of impurities. If a material with five electrons in the valence ring is added, the material is called a donor-type impurity. This type of material has one electron left over after it forms covalent bonds with four neighboring germanium or silicon atoms. Thus there will be an excess of electrons. We then refer to this kind of material as an N-type material.

If the germanium or silicon is doped with an impurity, called an accepter impurity, having three electrons in the valence shell, the impurity forms covalent bonds with the four neighboring germanium or silicon atoms. However, there will be a hole in one of the covalent bonds because the impurity has only three electrons available to form covalent bonds with four neighboring germanium and silicon atoms. This type of germanium or silicon is called P-type because there will be holes in the material, and these holes act as positive carriers.

Another point to remember is that when an electron is freed or when a hole captures an electron, the atoms involved become charged, or ionized. Thus throughout both N-type and P-type germanium or N-type and P-type silicon we have small regions of charge. However, the net charge on the crystal is zero and the charged regions are evenly distributed throughout the material.

SELF-TEST QUESTIONS

(a) How many electrons are there in a valence shell or ring in a silicon atom?

(b) What are the two types of material most widely used in semiconductor devices?

(c) What is meant by a covalent bond?

(d) How many covalent bonds will a single germanium or silicon atom establish?

(e) What is intrinsic conduction?

(f) Is intrinsic conduction desirable?

(g) In which type of conductor material, germanium or silicon, is intrinsic conduction the greatest?

(h) What is the greatest cause of an increase in intrinsic conduction in germanium?

(i) Which semiconductor material, silicon or germanium, has greater resistance?

(j) What is an N-type material?

(k) What is a donor material?

(l) Name two materials used as donors.

(m) What is P-type material?

(n) What is an accepter impurity?

(o) Name three types of accepter material.

(p) In N-type material what is the majority carrier?

(q) What are the majority carriers in the P-type material?

(r) When a donor impurity such as arsenic loses an electron in a semiconductor material, what happens to the arsenic and to a nearby atom that gains the electron insofar as their relative charge is concerned?

(s) Although there are small areas that have positive and negative charges in a doped semiconductor, what is the overall charge on the crystal?

Current Flow in Semiconductors

In order to understand how transistors operate, there are several new ideas that you must master. First, you must understand how current flows through both N-type and P-type semiconductor materials. Current flow through an N-type material is not too different from current flow through metals, which you have already studied. However, there is quite a difference in the way current flows through a P-type material.

When a P-type material is placed next to an N-type material, we have what is called a junction. The action that occurs at the point of contact between these two different types of materials is extremely important. It is this action that makes the transistor possible.

In this section of the lesson we will study how current flows through N-type and P-type materials. We need to understand current flow through both types of germanium or silicon to be able to understand how a junction works. In a later section we will see how a junction works. Later, we will see what happens in a transistor, which has two junctions.

This section is extremely important, and you should be sure that you understand it completely. Once you understand this material, it will be a simple step to see how transistors can be used to amplify signals.

DIFFUSION

As we have mentioned, adding impurities to pure germanium or silicon adds free electrons or holes. You might at first think that when there is no voltage applied there would be no motion of the free holes and electrons. However, this is not true--as you learned when we discussed intrinsic conduction, there is a certain amount of energy present in the crystal. This energy might be due to the temperature of the crystal, because as we pointed out before, even at room temperature the crystal does have heat energy. Motion of the free holes or electrons due to energy of this type is at random; in other words there is no net movement in any one direction. Holes move one atom at a time, and any hole may move from its starting location to any of the surrounding atoms. This means that a hole may start off in one direction as it moves from one atom to another, and then may move in almost the opposite direction as it moves to still a third atom. Similarly, electron movement is in a random direction; a given electron may move in first one direction and then in another.

When electrons and holes are in motion, the different carriers are moving in different directions. Remember that when there is a hole in one atom, and an electron moves from another atom to fill that hole, a new hole appears in the second atom. In other words, the electron has moved from the second atom to the first, whereas the hole has moved in the opposite direction from the first atom over to the second atom that gave up the electron. The result is that the effective current flow of any one carrier is cancelled by the movement of the other carrier and the resulting current flow in any direction is zero.

This random motion of carriers is called diffusion. It goes on at all times in a crystal whether there is a voltage applied to the crystal or not. Every effort is made in the design of transistors to keep this diffusion as low as possible.

DRIFT

Another type of carrier movement in semiconductors is known as "drift". This is the type of movement that is obtained when a voltage is applied across the crystal. Since the manner in which current flows through N-type and P-type material is different, let's consider them separately.

N-Type Material.

In Fig. 10 we have shown an N-type crystal with a voltage applied to it. The voltage difference supplied by the battery provides a force which makes it easier for the electrons to move in one direction than in the other. In an N-type material, the electrons will be attracted by the positive terminal of the battery. Because in the N-type material the electrons greatly outnumber the holes, they will carry the current.

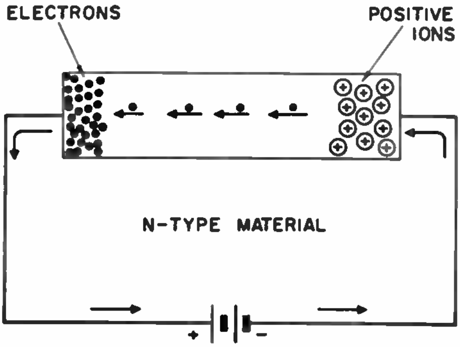


Fig. 10. N-type crystal with voltage applied to it.

When the electrons are attracted by the voltage applied to the positive terminal, they will move towards the positive terminal. When an electron moves away from the covalent bond that produced this free electron, it will leave behind an atom with a positive charge, which we call a positive ion. The electrons moving towards one end of the crystal set up a region that has a local negative charge, as shown in Fig. 10. This negative charge sets up a potential difference between that part of the crystal and the positive terminal of the battery. In other words the attraction of the positive battery terminal causes electrons to bunch up near the end of the crystal connected to the positive terminal. The electrons are drawn from the crystal into the wire connecting the crystal to the positive terminal of the battery by this potential difference.

Meanwhile, the electrons that have left the atoms at the other end of the crystal have left behind positive ions. This sets up a region of positive charge around the end of the crystal connected to the negative terminal of the battery so there will be a potential difference between the negative terminal of the battery and this region of positive charge. This potential difference will pull electrons from the wire into the crystal. These electrons replace the free electrons that were attracted to the positive terminal of the battery.

The number of electrons leaving the crystal at the end connected to the positive terminal of the battery will be exactly equal to the number of electrons entering the crystal at the end connected to the negative terminal of the battery. Since the crystal was electrically neutral be-

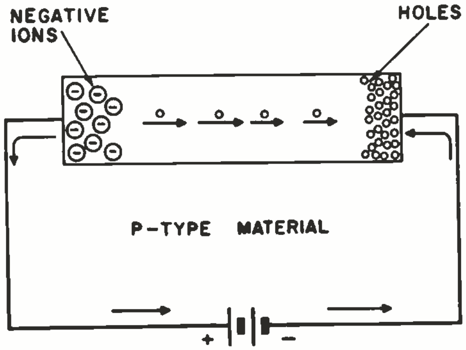


Fig. 11. P-type crystal with voltage applied to it.

fore the battery was connected and the number of electrons in it are constant, the crystal remains electrically neutral.

P-Type Material.

Conduction through P-type material is quite different from conduction through N-type material. In the P-type semiconductor, nearly all of the current is carried by holes. When a battery is applied to a P-type semiconductor, as shown in Fig. 11, the voltage causes the holes to drift towards the negative terminal. They are repelled by the positive potential applied to the one end of the material and attracted by the negative potential applied to the other end. When a hole starts moving away from the end of the material connected to the positive terminal of the battery, it moves because it is filled by an electron attracted from a nearby germanium atom.

When the hole in an accepter type atom is filled with an electron, the atom actually has one electron more than it needs to neutralize the charge on the nucleus. Thus, the atom has a negative charge, or in other words it becomes a negative ion. Negative ions that are formed near the end of the semiconductor that is connected to the positive terminal of the battery build up a region of negative charge at this end of the material. The extra electrons are drawn from these ions by the positive terminal of the battery, and a new hole is formed. These holes then drift towards the end of the semiconductor that is connected to the negative terminal of the battery, and build up a positive charge at this end of the semiconductor. This positive charge attracts free electrons from the external circuit. As a hole is filled with an electron, it disappears.

Thus in the P-type material, we have an electron flow in the external circuit from the negative terminal of the battery to the semiconductor, and from the semiconductor to the positive terminal of the battery. However, in the semiconductor itself, current flow is by means of holes, which drift from the end of the semiconductor that is connected to the positive terminal to the end that is connected to the negative terminal of the battery. Keep this point in mind, that even in the P-type material where conduction within the material is by holes (which are positive carriers) the current flow in the external circuit is by means of electrons and is in the conventional direction from the negative terminal towards the positive terminal of the battery in the external circuit.

There are several important differences between conduction in N-type semiconductors and conduction in P-type semiconductors. In both cases electrons flow from the external circuit into the crystal and then out of the crystal into the external circuit. However, in the N-type crystals, the excess electron produced when a donor atom forms covalent bonds with four germanium atoms is a free electron that can move about in the crystal. However, in the P-type material, the electrons are not free, but can move only to holes. Since a hole can capture an electron from any of its surrounding atoms, it is the hole that is free to move in any direction.

Another important difference between the N-type and the P-type materials is that a free electron moves approximately twice as fast as a hole. This affects the conductivity of the two types of semiconductor material. If we have two crystals, one an N-type and the other a P-type, if the N-type material has the same number of free electrons as the P-type has holes, the N-type will have a lower resistance because the free electrons can move approximately twice as fast as the holes in the P-type material.

SUMMARY

The important thing to remember from this section is that there are two types of carrier movement in semiconductors. The first is called diffusion and is simply a random movement of the carriers in the semiconductor material. The current flow produced by one carrier is cancelled by the movement of the other, and the resultant current flow in any direction is zero. Diffusion is the random motion of electrons or holes in a doped semiconductor due to the energy of the material.

The other type of movement we discussed is called drift. This type of conduction is produced when a potential is connected across a semiconductor. This potential can cause either electrons or holes to move within the semiconductor. In an N-type semiconductor, current flows through the semiconductor because of the movement of the free electrons produced by the donor atoms that have been added to the semiconductor material. In the P-type semiconductor, current flow through the crystal is by means of holes which are produced when an accepter-type impurity is added to the crystal.

In both cases current flow in the external circuit is from the negative terminal of the battery to the crystal and from the crystal to the positive terminal of the battery. In the N-type material, electron flow through the crystal is from the end connected to the negative terminal of the battery to the end connected to the positive terminal of the battery. In the P-type semiconductor, the holes flow from the end of the semiconductor connected to the positive terminal of the battery to the end of the semiconductor connected to the negative terminal of the battery.

The speed with which electrons move through N-type material is about twice the speed with which holes move through P-type material. Thus N-type material has better conductivity than P-type material, which means that N-type germanium will have a lower resistance than P-type germanium.

SELF-TEST QUESTIONS

(t) When an accepter-type impurity is added to a silicon or a germanium crystal, what type of carrier is produced in the crystal?

(u) What is diffusion?

(v) What is the name given to the movement of carriers in a semiconductor material when a voltage is applied across the material?

(w) What are the majority carriers in an N-type material and in what direction do they move when a voltage is applied across the material?

(x) What are the majority carriers in a P-type material and in what direction do they move through the material when a potential is applied across the material?

(y) When current is flowing through a crystal, will the crystal be charged?

(z) Is the rate of travel of electrons through N-type material the same as the rate of travel of holes through P-type material?

(aa) If you had two identical pieces of silicon and one was doped so that it was N-type material and the other doped so that it was P-type material, which would have the lower resistance?

Semiconductor Diodes

Just as there are diode tubes, there are also diode semiconductors. Some diode semiconductors are used as detectors; others are used as rectifiers in power supplies to change ac to pulsating dc. Diodes used as detectors are often referred to as signal diodes. Both germanium and silicon signal diodes are widely used. Diodes used for power rectification are almost exclusively silicon diodes. Relatively small silicon diodes can often handle considerably more current than a large rectifier tube.

A semiconductor diode is made by taking a single crystal and adding a donor impurity to one region and an accepter impurity to the other. This will give us a single crystal with a P section and an N section. Where the two sections meet, we have what is called a junction. Contacts are fastened to the two ends of the crystal so that a simple PN junction diode like the one shown in Fig. 12 is formed. For simplicity in the diagram we have represented the crystal as a box-like structure with one half being P-type material and the other half N-type material with a junction between the two sections.

This type of diode is called a junction diode. The action that takes place at the junction of the P-type crystal and the N-type crystal is what we will be most concerned with now. In order to understand how a junction diode works, you must learn something about the movement of electrons and holes near the junction. The movement of holes and

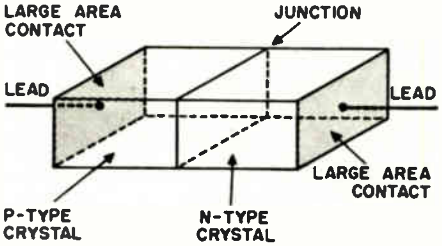


Fig. 12. Simple PN junction.

electrons will form what is called a depletion layer at the junction. Now let us see what the depletion layer is and how it is formed.

DEPLETION LAYER

Remember that in an N-type crystal there are free electrons, and in a P-type crystal there are free holes. Also remember that the electrons and holes are moving about the crystal with a random motion, called diffusion. In the PN junction diode, holes will be moving about in the P section and electrons in the N section. Some of the holes will cross over the junction from the P section into the N section and be filled by a free electron. Similarly, some of the electrons in the N-type material will diffuse across the junction and fill a hole in the P section.

When an atom in the N section loses an electron the atom becomes charged or ionized. It will have a positive charge because it will have one less electron than is needed to completely neutralize the charge on the nucleus. Thus electrons diffusing across the junction to fill a hole on the P side of the junction will leave behind atoms with a positive charge. At the same time, when an electron fills a hole on the P side, the atom will have one more electron than it needs to completely neutralize the charge on its nucleus, and therefore that atom will have a negative charge. Similarly, holes diffusing from the P side of the junction over into the N side will leave behind atoms with a negative charge. When the hole moves over to the N side, it will mean the atom into which it moves will have an electron missing and therefore it will assume a positive charge. When the hole leaves the P side of the junction because it has been filled by an electron, the atom that gains the extra electron will have a negative charge.

As a result of this diffusion across the junction, a region will build up around the junction called the depletion area. On the P side of the junction there will be an area where the holes are missing. On the N side of the junction there will be an area where electrons are missing; thus we get the name depletion layer.

The missing holes on the P side of the junction will result in a negative charge on the P side and the missing electrons on the N side will produce a positive charge on the N side of the junction. The negative charge on the P side of the junction will build up until it has sufficient amplitude to prevent any further electrons from the N side from crossing the junction to the P side. Remember that the negative charge built up on the P side of the junction will repel electrons from the negative side. Similarly, the positive charge built up on the N side of the junction will prevent holes from the P side from crossing the junction into the N-type material. Thus this area, which is called the depletion layer because it is short holes on one side and electrons on the other side, is also sometimes called the barrier layer, because the charges built up form barriers to prevent any further diffusion of holes or electrons across the junction. It is also sometimes called a potential barrier because a negative potential is built up on the P side of the junction and a positive potential is built up on the N side of the junction.

The action taking place at the junction is quite important and is illus-

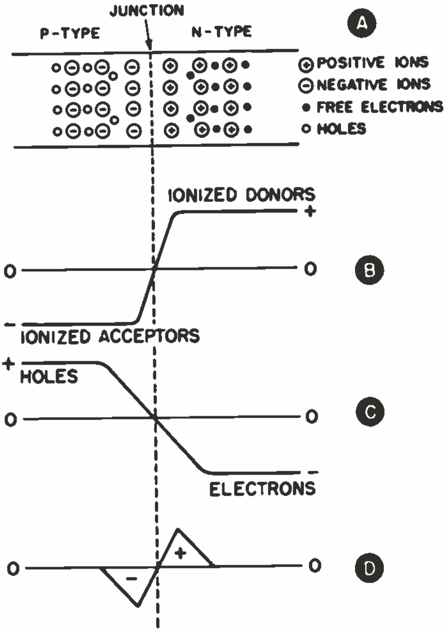


Fig. 13. (A) locations of ions and carriers at a PN junction; (B) charges at junction due to ionized impurity atoms; (C) carrier charges available; (D) resultant charges.

trated in Fig. 13A. On the P side of the junction we have shown ionized atoms that have a negative charge because the holes in these atoms have been filled by electrons. The holes have escaped and travelled or diffused across the junction into the N-type material. On the N side of the junction we have shown atoms that are ionized and have a positive charge. These atoms have a positive charge because they have lost electrons. These electrons have diffused across the junction into the P-type material. Thus we have a charged area at the junction. The negative charge on the P side of the junction prevents any further movement of electrons from the N-type material across the junction into the P-type material, and the positive charge on the N side of the junction prevents any further movement of holes from the P-type material across the junction into the N-type material.

The charge on the ions is shown in Fig. 13B. Notice that on the P side of the junction the atoms that have lost holes by gaining electrons have a negative charge. At the junction the potential drops to zero and then reverses on the N side where the ionized atoms have a positive charge because they have lost electrons.

In Fig. 13C we see the carrier charges which are available to neutralize the ionized atoms. At some distance from the junction there are holes with a positive charge. However, as we approach the junction, the concentration of these holes decreases because they are repelled away from the junction by the positive ions on the N side of the junction. On the N side of the junction at some distance from the junction we have many electrons available, but as we approach the junction, the charge drops to zero because these electrons are repelled away from the junction by the negative ions on the P side of the junction.

The resultant charges on the crystal are shown in Fig. 13D. As before, the crystal will have a tendency to remain neutral, or in other words not to have any charge. Some distance from the junction the atoms will have exactly the correct number of holes and electrons so that the net charge on the atoms is zero. As we approach the junction, the negative ions on the P side will result in an area in the crystal that has a negative charge. As we move closer to the junction, the charge will drop to zero so that at the junction itself the net charge on the atoms is zero. Then the charge builds up in a positive direction on the N side of the junction due to the ionized atoms that have lost electrons. As we move away from the junction we again reach a region where the atoms have exactly the correct number of electrons to neutralize the charges on the nucleus so the net charge in that area will be zero.

So far we have been discussing only the action of the majority carriers at the PN junction. However, there is one other important point we must consider in order to completely understand what happens at the junction. You will remember some time ago that we mentioned that holes and electrons are in a continuous state of motion in the crystal due to the energy of the crystal. For example, even at room temperature, the crystal contains a certain amount of heat energy and this energy is sufficient to cause motion of both electrons and holes. In the N-type material an electron will leave an atom creating a hole. This hole will be filled by an electron from another atom. Thus we have the continual formation of hole-electron pairs. Away from the junction, this formation of hole-electron pairs does not have any effect on the carrier concentration in the crystal. In other words, the holes will remain the majority carriers in the P-type region, and the electrons will remain the majority carriers in the N-type side of the crystal.

However, as we mentioned previously, both holes and electrons are involved in conduction at all times. There are minority carriers in both regions - holes in the N region and electrons in the P region. The holes produced in the N region near the junction will be attracted by the negative ions on the P side of the depletion layer at the junction and pass across the junction. These holes will tend to neutralize the ions on the P side of the junction. Similarly, free electrons produced on the P side of the junction will pass across the junction, and neutralize positive ions on the N side of the junction. This is an example of intrinsic conduction, conduction due to the formation of hole-electron pairs, and as we mentioned, this type of conduction is undesirable.

Now let us consider what happens due to the minority carriers crossing the junction. Holes crossing the junction from the N-type material to the P-type material tend to neutralize the positive ions on the P side of the junction. Similarly, electrons traveling from the P side of the junction to the N side of the junction tend to neutralize the negative ions on the N side of the junction. This flow of minority carriers across the junction weakens the potential barrier in the region around the atoms they neutralize. When this happens, the majority carriers are able to cross the junction at the location of the neutral atom. This means that the holes from the P side will cross over to the N side, and electrons from the N side will cross over to the P side.

The result is that we have both holes and electrons crossing the junction in both directions. The hole that crosses from the N side to the P side due to intrinsic conduction permits a hole to cross from the P side to the N side by diffusion. Similarly, an electron that crosses the junction from the P side to the N side due to intrinsic conduction permits another electron to go from the

N side to the P side by diffusion. The result of the holes and electrons crossing the junction in both directions is that these movements cancel each other, and the charge on the atoms at the junction remains the same. This movement of holes and electrons in both directions contributes nothing towards the net charge or current flow through the junction. However, the flow across the junction will produce a certain amount of heating; it will in effect use up a percentage of the total capacity of the junction to pass current so that the net result is to reduce the amount of useful current the diode can pass.

BIASED JUNCTIONS

If a battery is connected to the ends of a PN junction diode, the battery potential will bias the junction. If we connect the battery so that its polarity aids the flow of current across the junction, we call it a "forward-biased junction", whereas if we connect the battery so that the polarity opposes the flow of current across the junction, we say that it is a "reverse-biased junction". In both cases there will be some current flow through the junction, but as you might expect, with forward bias the current flow will be higher.

In order to understand how transistors work, you must understand both conditions of bias. You will study each condition separately, because the action that occurs at the junction is quite different in the two cases. In the operation of transistors both types of bias are used, and therefore it is important that you understand what happens in each case.

Forward Bias.

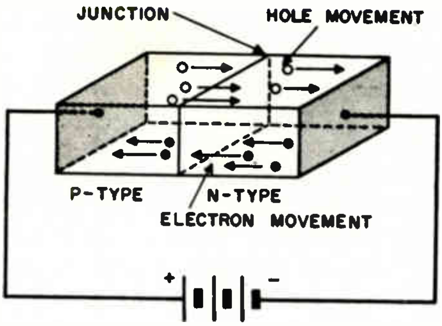


Fig. 14. Forward-biased junction.

When we connect a battery to a junction diode with the polarity such that it aids the movement of majority carriers across the junction, we say that the diode is forward biased. A forward-biased junction is shown in Fig. 14. Here the positive terminal of the battery is connected to the P-type section and the negative terminal of the battery is connected to the N-type section. Now let us consider what happens to the depletion layer at the junction of the P and N-type material when the battery voltage is applied.

The positive voltage connected to the end of the P-type crystal will repel holes towards the junction and attract electrons from the negative ions near it. The combination of holes moving towards the junction to neutralize charged negative ions on the P side of the junction and electrons being taken from the negatively charged ionized accepter atoms tends to neutralize the negative charge on the P side of the junction.

On the N side of the crystal, the negative terminal of the battery repels electrons towards the junction. These electrons tend to neutralize the positive charge on the donor atoms at the N side of the junction. At the same time the negative potential at the N side of the crystal attracts holes away from the charged positive ions on the N side of the junction. Both of these actions tend to neutralize the positive charge on the donor atoms at the junction.

The effect of the battery voltage is to reduce the potential barrier at the junction and allow more majority carriers to cross the junction. This means that we will have more electrons flowing from the N-type material across the junction to the P-type material and to the positive terminal of the battery and more holes traveling from the P-type material across the junction to the N-type material and towards the end of the crystal connected to the negative terminal of the battery. You know that we already had a certain number of intrinsic minority carriers crossing the junction, but now the majority carriers outnumber them, so there will be a steady current flow from the negative battery terminal, through the N-section, across the junction and through the P-section, to the positive battery terminal.

Placing a forward bias on a junction diode drives majority carriers back into the depletion layer and allows conduction across the junction. If the battery voltage is increased, more carriers will arrive at the junction and the current flow will increase. Eventually, if we continue to increase the battery voltage, we will reach a point where all the charges at the junction are neutralized. When this happens, the holes will fill the P-type region right up to the junction; electrons will fill the N-type region up to the junction; and the only limit to current flow through the diode will be the resistance of the material on the two sides of the junction.

It is important for you to remember that in a forward biased junction conduction through the crystal will be by the majority carriers. Any intrinsic conduction across the junction will be by minority carriers and this will subtract from the total current flow across the junction. Increasing the forward bias will increase the current flow across the junction until the point is reached where all the charges at the junction are neutralized, at which time the potential barrier will disappear, and current flow across the junction will be unhindered by any potential across the junction.

Reverse Bias.

If we reverse the battery connections we will have what is known as reverse bias. This condition is shown in Fig. 15.

With a reverse bias applied to a junction diode, the negative terminal of the battery will be connected to the P-type section, and will attract holes away from the junction, and increase the shortage of holes on the P side of the junction. At the same time the positive terminal of the battery is connected to the N-type section of the crystal and this

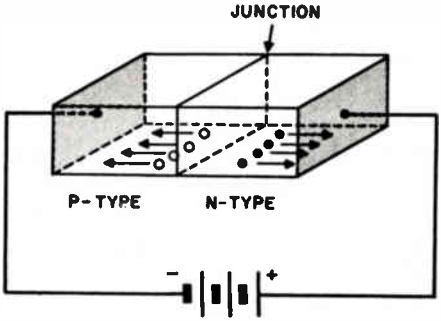


Fig. 15. Reverse-biased junction.

terminal will attract electrons away from the junction and increase the shortage of electrons on the N side of the junction. This movement of holes and electrons away from the junction will in effect result in an increased potential barrier at the junction. The increase in potential barrier occurs because there will be fewer holes on the P side of the junction to neutralize the negative ions and fewer electrons on the N side to neutralize the positive ions formed on this side of the junction. The increase in potential barrier will help prevent any further current flow across the junction due to majority carriers.

The current flow across the barrier, however, is not zero because we will still have minority carriers crossing the junction. Holes forming in the N side of the depletion layer will be attracted by the negative potential applied to the end of the P-type section of the crystal, and electrons breaking loose from their nuclei in the P side of the depletion layer will be attracted by the positive voltage applied to the end of the N-type section of the crystal.

We had this situation when there was no bias applied to the junction. Holes from the N side would cross over to the P section, and electrons from the P side would cross over to the N section. However, when there was no bias applied to the crystal, these minority carriers would neutralize ions near the junction and allow the majority carriers to cross the junction. However, since the minority carriers are now attracted away from the junction by the potential applied to the crystal, all of the minority carriers do not remain near the junction to neutralize charged atoms so they no longer allow the passage of an equal number of majority carriers in the opposite direction. This means that the flow of minority carriers across the junction is not fully offset by a flow of majority carriers in the opposite direction. Therefore, there will be a small current flow across the junction due to the minority carriers crossing the junction. This current flow is very small and nearly constant at all normal operating voltages in signal diodes and power rectifier diodes. However, as you will see later, there are certain types of diodes where this reverse current can increase quite rapidly even at low voltages.

It is important to realize that when a reverse bias is applied to a junction diode, the bias increases the potential difference across the junction and makes it more difficult for majority carriers to cross the junction. However, some minority carriers will still cross the junction with the result that there will be a small current flow across the junction due to the minority carriers.

COMPARISON OF JUNCTION DIODES AND VACUUM TUBES

Although the operation of junction diodes designed for use as rectifiers is quite different from the operation of vacuum tubes, they can perform identical tasks and therefore some comparison of the most important characteristics of both is in order.

When there is no voltage applied to a junction diode, the net current flow across the junction is zero. On the other hand, in a vacuum tube, even though there may be no voltage applied to the plate of the tube, some of the electrons will leave the cathode with sufficient velocity to travel across the space between the cathode and the plate and strike the plate. This will result in a small current flow from the cathode to the plate of the tube even though there may be no voltage applied to the plate of the tube.

We can consider applying a positive voltage to the plate of a vacuum tube and a negative voltage to the cathode as being similar to placing a forward bias on a junction diode. Under both circumstances there will be a current flow through the diode. In this respect the two are similar.

When the voltages applied to the diode vacuum tube are reversed so that there is a negative voltage applied to the plate and a positive voltage to the cathode, there will be no current flow at all through the tube. The negative potential on the plate of the tube will repel electrons from the plate. This reverse voltage situation is similar to a reverse bias across a junction diode. However, when we place a reverse bias across a junction diode, there will be some current flow across the junction due to the conduction by minority carriers. As long as the breakdown voltage of the junction diode is not exceeded, this current will be very small and almost constant. In a good diode, it is so small it can be ignored.

We can summarize the characteristics of diode vacuum tubes and junction diodes as follows: with forward bias both the tube and junction diodes will conduct. With reverse bias, the tube will not pass current; the junction diode will pass a small current. With no bias, the tube will pass a small current; the junction diode will not.

ZENER DIODES

In junction diodes designed for use as rectifiers we must be careful not to exceed the rated reverse voltage of the diode. In other words, if we place too high a reverse bias across the junction, the junction will break down, a very high current will flow across the junction for a short while, and the diode will be destroyed. However, in some diodes we make use of this reverse current due to minority carriers. In diodes of this type both the P section and the N section are doped quite heavily. The junction between the P section and the N section is considerably larger than the junction of the rectifier-type diode, so that when the diode begins to pass current in the reverse direction, it can pass it over a larger area and thus avoid destroying the diode. This type of diode is used as a voltage reference and is referred to as a voltage-reference diode or a Zener diode.

In the Zener diode, the current remains small with low reverse voltages. At a certain voltage, called the breakdown voltage, the current will increase rapidly with any further increase in voltage.

The breakdown voltage can be varied by varying the diode material and construction. Zener diodes can be made with a breakdown voltage as low as 1 volt, up to breakdown voltages of several hundred volts. The current that can pass through any Zener diode before the diode will be damaged will depend upon the junction area and the methods used to keep the diode cool.

In a circuit where a Zener diode is used, it will be used as a voltage reference or a voltage regulator. As the reverse voltage across the diode

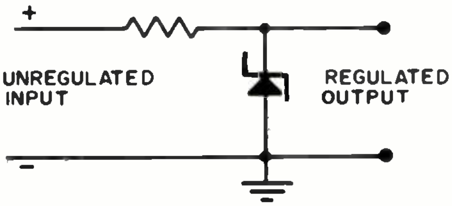


Fig. 16. Circuit using Zener diode as a voltage regulator.

increases, a very small reverse current will flow, and the value of this current will remain essentially constant until the breakdown voltage is reached. At that voltage, any further increase in voltage will result in a large increase in current across the junction. This large increase in current tends to produce a voltage drop in other components in the circuit so that the voltage across the diode will remain essentially constant. Thus a Zener diode can be used as a voltage regulator in a circuit such as shown in Fig. 16. If the input voltage tends to rise, the current through the diode will increase. This increase in current will increase the voltage drop across the resistor so that the output voltage will remain essentially constant. The fact that with even a very small increase in voltage the current through the diode will increase substantially means that the voltage across the diode will remain almost constant.

In some other applications the diode may be used as a reference voltage. This simply means that a Zener diode with a given breakdown voltage is used in a circuit like Fig. 16. The voltage applied to the diode will remain essentially constant. In some circuits, we may compare the voltage across a resistor or another part with the voltage across the Zener diode.

TUNNEL DIODES

A tunnel diode is a highly doped junction diode made either of germanium or gallium arsenite. Both the N region and the P region of the diode are very highly doped. As a result of the high doping, the depletion region around the junction is extremely narrow. Because of the narrow depletion region, holes and electrons can cross the junction by more or less tunneling from one atom to another. The exact action of the charges crossing the junction is somewhat difficult to visualize, but the characteristics of the tunnel diode are comparatively simple. With a reverse bias across the junction, current across the junction increases quite rapidly. If the reverse bias is dropped to zero the current will drop back to zero. If the forward bias, starting at zero and gradually increasing, is placed across the junction, current flow across the junction will increase at essentially the same rate as it increased with a negative bias. The current across the junction will increase quite rapidly as the forward bias is increased until a rather sharp peak is reached. If the forward bias is increased beyond this point, then the current begins to decrease.

As the forward bias is increased still further, the current across the junction decreases, forming a curve such as shown in Fig. 17. This decreasing current, with increasing voltage, results in a negative resistance characteristic. It might be difficult to visualize what a negative resistance is, but you will remember from Ohm's Law that re-

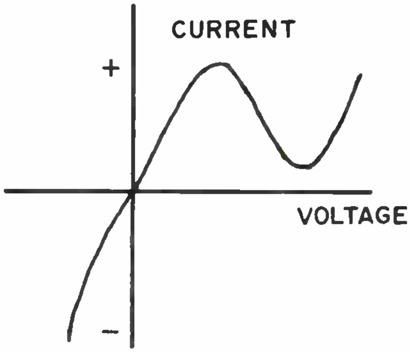


Fig. 17. Voltage-current relation in a tunnel diode.

sistance is equal to voltage divided by current. In a circuit where we have resistance, if the resistance is constant and the voltage increases, then the current must increase; and similarly if the voltage decreases, the current must decrease. Here in the tunnel diode we have a region where the opposite happens. If the voltage increases, the current decreases and if the voltage decreases, the current increases. Thus we have something in the circuit that is giving us the opposite effect of resistance; we call this negative resistance. You will remember that resistance in a circuit introduces losses. It is the resistance in a resonant circuit that prevents a resonant circuit from continuing to oscillate once it has been excited into oscillation. However, if we can put something with negative resistance in the circuit, for example a tunnel diode, since it has the opposite effect of resistance, then the circuit should continue to oscillate. Tunnel diodes can be used for this purpose.

At the present time, tunnel diodes have not appeared in the commercial entertainment-type equipment. However, it is probably just a matter of time until they are used; therefore you should at least have some basic knowledge of what the tunnel diode is.

P-I-N DIODES

The p-i-n diode, which is an abbreviation for positive-intrinsic-negative, is a new diode which is used in a somewhat different manner from the diodes you have studied previously. Rather than being used as a detector or rectifier, this diode is used primarily as a variable resistor. It is a special type of diode, and its resistance can be controlled by applying a dc bias to it. With a reverse bias across the diode, it has a very high resistance. With no bias, its resistance drops to about 7000 ohms, and with forward bias it drops to a comparatively low value.

The diode is particularly useful in circuits where the strength of a signal must be controlled. Its first commercial use has been in fm equipment and it is used in order to prevent extremely strong fm signals from causing overloading in the fm receiver. A dc bias is applied to the diode and the amplitude of the bias depends upon the strength of the signal. When a very strong signal is applied, the reverse bias applied to the diode increases so that the resistance of the diode increases. This reduces the strength of the signal fed to the mixer and i-f stages in the receiver and thus prevents overloading, particularly in the last stage of the receiver.

At this time p-i-n diodes are not widely used in commercial applications, but you should be aware of how the diode is used, because it is quite likely that it will be widely used in the future.

POINT-CONTACT DIODE

Another semiconductor diode is the diode detector used in many TV receivers. This detector is a point-contact diode. A cut-away view of a point-contact diode is shown in Fig. 18 along with the schematic symbol.

The point-contact diode is made of a small piece of either N-type or P-type germanium or silicon. N-type germanium or silicon is used more often than P-type. In manufacturing a diode of N-type material, a large contact is fastened to one side of the crystal. A thin wire, called a catswhisker, is attached to the other side of the crystal. When the catswhisker is attached to the N-type crystal, a small region of P-type material is formed around the contact as shown in Fig. 19. Thus we have a PN junction that performs in much the same way as the junctions we have already discussed.

The characteristics of the point-contact diode under forward and reverse bias are somewhat different from those of the junction diode. With forward bias the resistance of the diode is somewhat higher than that of a junction diode. With reverse bias the current flow through a point-contact diode is not as independent of the voltage applied to the crystal as it was in the junction diode. In spite of these disadvantages, the point-contact diode makes a better detector than the junction diode, particularly at high frequencies because the point-contact diode has a lower capacity than the junction diode.

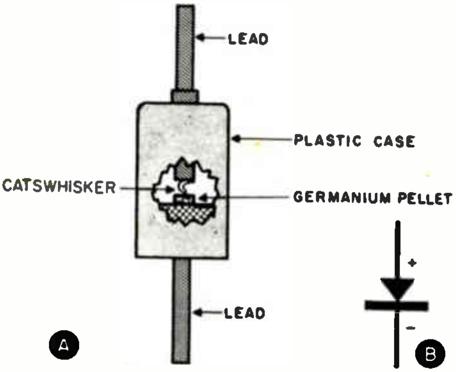


Fig. 18. (A) cut-away view of crystal rectifier. (B) schematic symbol of it.

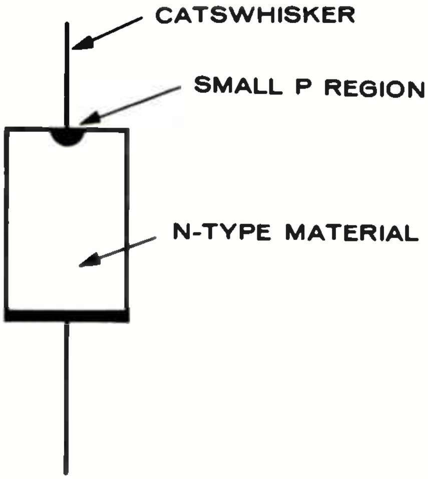


Fig. 19. Sketch of a point-contact diode showing where the P-type germanium is formed around the catswhisker.

SUMMARY

Again this is a very important section, so you should review it before going on to the next section. Make sure you understand what the depletion layer is and why it is formed. Also be sure you understand the movement of holes and electrons across a PN junction when no voltage is applied to the junction.

Current flow across the junction with both forward and reverse bias is important. With forward bias current flow across the junction is by majority carrier, and with reverse bias it is by minority carrier.

SELF-TEST QUESTIONS

(ab) What are the two principal uses of semiconductor diodes?

(ac) What is the depletion layer?

(ad) What do we mean by the potential barrier?

(ae) Does the crystal develop an overall charge as a result of diffusion across the junction?

(af) Do the minority carriers crossing the junction have any adverse effect on the diode?

(ag) What do we mean when we say the junction is forward biased?

(ah) What do we mean when we say a junction is reverse biased?

(ai) What is the difference between vacuum-tube diodes and semiconductor diodes insofar as current flow through the diode is concerned when no voltage is applied?

(aj) What is the difference between current flow in a semiconductor diode and a vacuum tube under reverse voltage conditions?

(ak) What is a Zener diode, and what is it used for?

(al) What is a tunnel diode?

(am) What is a p-i-n diode?

Semiconductor Triodes

Even though a junction diode will pass current in both directions, it passes current in one direction much better than it does in the other, and therefore it can be used as a detector. The tunnel diode can be used as an oscillator, and in some special circuits as an amplifier; however, its usefulness in these applications is limited. In most cases, the semiconductor diode is like the vacuum-tube diode; it is more or less useless insofar as amplifying a signal is concerned. In order to amplify a signal, a three element semiconductor is needed. Three element semiconductors that are capable of amplification are called transistors.

There are a number of different types of transistors in use today. The characteristics of the different types vary appreciably, but if you understand the operation of one type, you can understand how the others work without too much difficulty. We started our explanation of. semiconductor devices with a junction diode, so we will start our study of triode semiconductors with a study of the junction transistor. You'll find that most of the transistors you will study operate in a manner similar to the basic junction transistor. The most notable exception to this is the field-effect transistor which you will study later in this lesson.

JUNCTION TRANSISTORS

Both germanium and silicon are used in the manufacture of junction transistors. A triode-junction transistor is made up of single semiconductor crystals with three different regions. The center region is made up of one type of germanium or silicon, and the two end regions are made up of the other type of germanium or silicon. In other words, in one type of junction transistor the center has had accepter-type region impurities added and the two end regions have had donor-type impurities added. In the other type of junction transistor, the center region has had donor-type of impurities added and the two end regions have had accepter-type impurities added.

The center region of the transistor is called the base. This is usually a comparatively thin region. One of the end sections is called the emitter and the other end section is called the collector.

If the center section of the crystal has been treated with donor-type impurities, then the center section becomes N-type germanium in the case of a germanium transistor or N-type silicon in the case of the silicon transistor. In this case, the two end sections will be treated with accepter-type impurities and they will both become P-type germanium or P-type silicon. We call this type of transistor a PNP transistor. We can have both germanium PNP and silicon PNP transistors. An example of this type of junction transistor is shown in Fig. 20A along with the schematic symbol used to identify it.

The other type of junction transistor is an NPN type. This type of transistor is produced by treating the center section with an accepter-

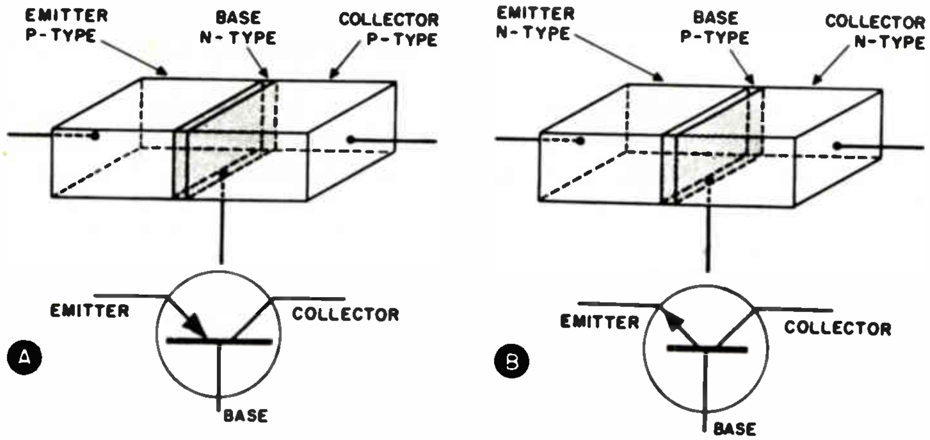


Fig. 20. (A) shows a PNP junction transistor and its schematic symbol. (B) shows an NPN junction transistor and its schematic symbol.

type impurity to produce P-type germanium or silicon, and the two end sections with a donor-type of impurity to produce N-type germanium or silicon. This is the type of junction transistor shown in Fig. 20B along with the schematic symbol for it. As in the case of the PNP transistor, we can have either an NPN germanium transistor or an NPN silicon transistor.

Notice that the schematic symbols for the PNP transistor and the NPN transistor are different. In the PNP transistor the arrow used to represent the emitter points down toward the base, whereas in the NPN transistor the arrow on the emitter points up away from the base. Thus on a schematic diagram of a piece of equipment using junction transistors, you can tell from the direction in which the arrow is pointing whether the transistor is a PNP or an NPN transistor.

There are several different ways of manufacturing junction transistors, and often you hear these transistors referred to by the manufacturing method used. For example a junction transistor might be called a grown junction, a fused junction, an alloy junction or a diffused junction. All these names simply describe the manufacturing process used to make the transistor. They are all junction transistors and all operate on the same basic principle. This does not mean to imply that the characteristics of all junction transistors are the same; they are not. There are wide differences in characteristics just as there are in various triode vacuum tubes.

To understand how junction transistors work, you must understand junction diodes. Because it is so important that you understand the formation of the depletion layers at the junctions we will review the explanation of what happens at the junctions in explaining the junction transistors. The big difference between the junction transistor and the junction diode is that in the transistor there are two junctions close together in the same crystal. One of these junctions is biased in the forward direction and the other in the reverse direction and the presence of one junction affects the operation of the other.

PNP TRANSISTORS

In transistor operation, the emitter-base junction is always biased in the forward direction and the collector-base junction is biased in the reverse direction. Each of the two junctions by itself behaves just like the PN junction already described.

Let us consider what happens in the PNP transistor before any voltages are applied to the transistor.

At the junctions, holes from the P-type emitter section and the P-type collector diffuse across the junctions into the base. At the same time, electrons from the base diffuse across the junctions into both the emitter and the collector. The holes diffusing into the base place a positive charge on the atoms near the junctions. Similarly the electrons diffusing from the base into the emitter on one side of the base and the collector on the other side of the base place a negative charge on the atoms on the emitter and collector sides of the junctions. These charged atoms, which are called ions, will repel electrons and holes from the region of the junctions. The positively charged ions in the base will repel holes in the P sections away from the junctions. Similarly, the negatively charged ions in the emitter and collector will repel electrons away from the junctions in the base. Thus we have two depletion layers formed, one at the emitter-base junction and the other at the base-collector junction.

You will remember that when we discussed the junction diode, we mentioned that hole-electron pairs will be formed in the depletion region. The minority carriers formed in each section can cross over the junction. For example, the electrons released in both the emitter and the collector regions will cross the junctions into the base. These electrons will neutralize a few ions in the base region. When these ions are neutralized they will allow majority carriers from the emitter and collector to cross the junctions. In other words, there will be holes from the emitter and holes from the collector crossing the junctions into the base. Similarly, holes, which are the minority carriers in the base region (and are formed in the depletion layer) will cross the junctions into the emitter and collector. When these holes cross the junctions they will neutralize some of the nega-

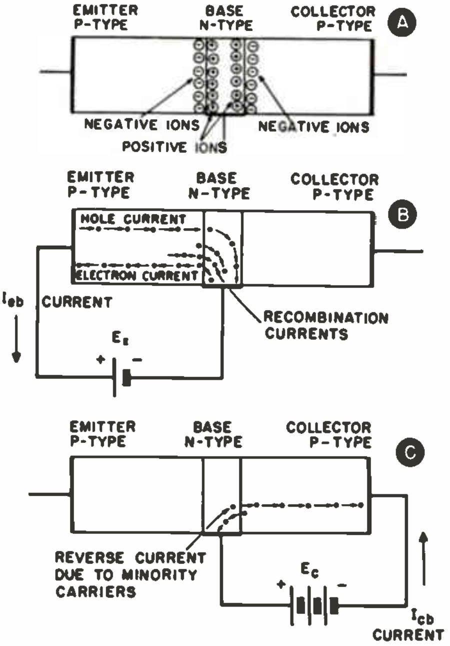


Fig. 21. (A) the formation of ions at the junctions of a PNP transistor. (B) the current flow in the emitter-base circuit and (C) in the collector-base.

tively charged ions in the emitter or collector region and allow some electrons to flow from the base into either the emitter or the collector. Thus, because of the intrinsic conduction due to hole-electron pairs being formed in the depletion region there will be some flow of carriers across the junction. However, the flow of majority carriers across the junction will be exactly equal to the flow of minority carriers across the junction so that the net current flow across each junction will be zero.

The potential barriers formed at the junction regions are shown in Fig. 21A. Notice that the charges formed at the junction are similar to those formed at a junction diode; we simply have two junctions to consider in a transistor.

Now when we place a forward bias between the emitter and the base we have an arrangement like that shown in Fig. 21B. Here the positive voltage applied to the end of the P-type emitter repels holes towards the junction. These holes tend to neutralize the negative charge on the ions on the emitter side of the junction. The holes are formed at the end of the P-type section by electrons being taken out of this section by the positive potential applied to it. At the same time the positive potential applied to the emitter attracts the electrons that have given the ions on the P side of the junction their negative charge. This also weakens the negative charge on the emitter side of the junction.

At the base, which is connected to the negative side of the battery, the holes will be attracted toward the negative terminal of the battery, and electrons will be pushed towards the depletion layer. The pulling of holes away from the depletion area and pushing electrons into the depletion area tends to neutralize the charge on the base side of the junction.

The net effect of biasing in a forward direction is to neutralize the charges on each side of the junction and allow current to flow across the junction. Current flow is by majority carriers: electrons from the N-type base region and holes from the P-type emitter region.

Thus in the emitter-base circuit we have electrons flowing from the negative terminal of the battery to the base, through the base, across the junction, and through the emitter to the positive terminal of the battery. At the same time we have holes being produced because electrons are being pulled out of the P-type emitter by the positive potential applied to it. The holes will move through the emitter, across the junction into the base and to the point where the base is connected to the negative terminal of the battery. At this point they will pick up electrons and disappear.

Not all the electrons going from the base to the emitter will reach the positive terminal of the battery. Some of these electrons will recombine with holes in the emitter. Similarly, some of the holes traveling from the emitter into the base will pick up an electron in the base. This current flow across the junction is called a recombination current, and the transistor is designed to keep this current as low as possible. In other words we want the holes and electrons crossing the junction to reach the terminals connected to the battery.

Now let us consider the other junction, the base-collector junction. This junction is reverse biased as shown in Fig. 21C. Here again we have a depletion layer at the junction. Also we have minority carriers being formed in the depletion layer. However, holes that are formed in the base will cross the junction and then instead of neutralizing a negatively charged atom near the junction in the collector, these holes will be attracted by the negative potential applied to the collector. Similarly, electrons formed in the depletion layer of the P-type collector will cross the junction and be attracted by the positive potential applied to the base. Thus we have a current flow due to the minority carriers. Electrons in the depletion layer of the collector section will cross the junction and flow through the base to the positive terminal of the battery. Meanwhile electrons from the negative terminal of the battery will fill holes that are moving from the base, across the junction, and through the collector to the negative terminal.

Thus you can see that while we have a current by majority carriers due to the forward bias applied between the emitter and the base, we also have a small current flowing through the base-collector circuit by minority carriers due to the reverse bias applied between the base and the collector. Now let us see how the two junctions affect each other.

A transistor with both biased junctions is shown in Fig. 22. Here we have a number of different currents flowing. In the emitter-base circuit we have current flowing due to the forward bias applied between these two. Electrons will flow from the negative terminal of the battery into the base, across the junction, and through the emitter to the positive terminal of the battery. We will also have some holes formed in the P-type emitter section due to electrons being pulled out of this section by the positive terminal of the battery. Some of these holes will cross the junction into the N-type base where they will pick up an electron and disappear. This current is called the recombination current.

Many of these holes will cross the base and flow through the collector, because the negative terminal of the battery connected between the base and collector will attract them. This movement of holes accounts for most of the current flow in the emitter and collector circuits. Remember that holes are being continually formed in the P-type emitter because electrons are

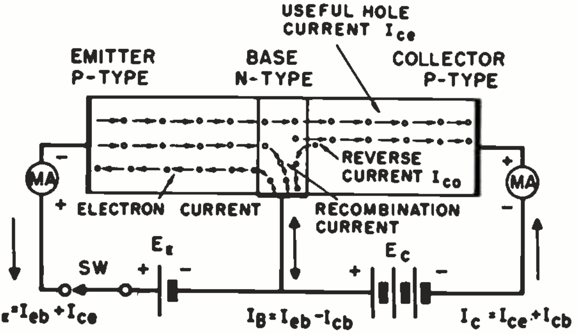


Fig. 22. Current flow and carrier movement in a PNP junction transistor.

being pulled out of the emitter by the positive potential applied to it. These holes will continually move through the emitter, and into the base. Here some of them will combine with electrons and disappear, but the majority of them will flow through the collector to the negative terminal of the collector where they will be filled by electrons and disappear.

Another current that will flow is reverse current I_{CO} that flows in the base-collector circuit. This is due to the formation of minority carriers in the depletion layer.

Thus we have four currents flowing in the PNP junction transistor. The largest of these currents is due to the movement of holes from the emitter through the base into the collector to the negative terminal of the battery connected to the collector. We have in addition to this current three small currents flowing. We have the current due to the electron movement from the negative terminal of the emitter-base battery into the base, across the junction and through the emitter to the positive terminal of this battery. We have the recombination current due to holes combining with electrons in the base, and we have the reverse current due to hole-electron pairs being formed in the depletion layer of the base-collector junction. The directions of the different movements of holes and electrons are marked in Fig. 22.

NPN TRANSISTORS

Although the operation of the NPN transistor is somewhat different from that of the PNP type, if you understand how the PNP transistor works, you should have no difficulty understanding the NPN. Again, we can start our study of this type of transistor by considering what happens at the junctions, remembering that the action at the junction is similar to the action we studied at the simple PN diode junction.

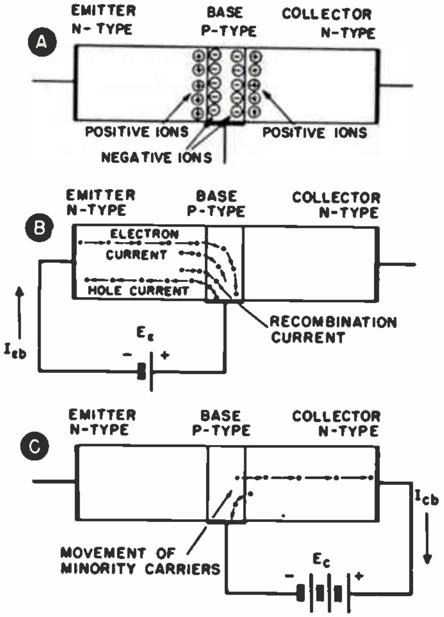


Fig. 23. (A) the formation of ions at the junctions of an NPN transistor. (B) the current flow in the emitter-base circuit and (C) in the collector-base circuit.

Let us first consider the action of the holes and electrons before any voltages are applied to the transistor. The charges that will be built up are shown in Fig. 23A. Remember that holes from the base will diffuse across both junctions into the emitter and the collector. Similarly electrons from the emitter and electrons from the collector will diffuse across the junctions into the base. The holes and electrons diffusing across the junctions will charge atoms near the junction. Holes crossing the junctions into the emitter and the collector will ionize the atoms on the emitter and collector sides of the junctions so that they will have positive charges. Similarly, electrons diffusing across the junctions into the base will ionize atoms in the base near the junctions so that they will have negative charges. Thus we will have potential barriers at the junctions. This is the same kind of potential barrier that we found existed across the PN junction in a diode.

The positively charged ions on the emitter and collector sides of the junctions will force holes in the base away from the junction. Similarly the negatively charged atoms on the base side of the junctions will force electrons in the emitter and collector away from the junction so that at the junctions we have a depletion layer.

Now let us consider what happens when we apply a forward bias between the emitter and the base by connecting a battery between the two as shown in Fig. 23B. Notice that the negative terminal of the battery is connected to the end of the emitter, and the positive terminal is connected to the base.

Now, several things happen. The negative potential applied to the emitter will force electrons toward the junction. At the same time the negative potential will attract holes away from the junction. Both of these actions tend to neutralize the positively charged ions on the emitter side of the junction. At the same time the positive terminal of the battery that is connected to the base will attract electrons away from the negatively charged atoms on the base side of the junction. In addition, the positive potential will repel holes towards the junction so that these two actions tend to neutralize the charge on the base side of the junction.

Once the potential barrier at the junction is weakened, electrons can flow from the negative side of the battery into the emitter, through the emitter, and across the junction into the base and from the base to the positive side of the battery. At the same time the positive terminal of the battery can extract electrons from the base, forming holes. Holes are then repelled toward the junction, across the junction, and through the emitter toward the end of the emitter that is connected to the negative terminal of the battery. Here the holes will pick up electrons and disappear. Thus we have a current flow through the emitter-base circuit as shown in Fig. 23B.

Now let us consider what happens when we apply a reverse bias between the base and the collector. Here the negative potential applied to the base will pull holes away from the junction, and the positive potential applied to the collector will pull electrons away from the junction. Thus the negative charge on the base side of the junction will be increased, and the positive charge on the collector side of the junction will be increased so that the potential barrier at the junction will be increased. This will prevent any current flow through the base-collector circuit due to the majority carriers.

At the same time electrons, which are minority carriers, will break loose from their nuclei in the depletion layer on the base side of the junction and will be attracted by the positive potential applied to the collector. They will cross the junction and flow through the collector to the terminal connected to the positive side of the battery, as shown in Fig. 23C. At the same time holes formed on the collector side of the junction in the layer will be attracted by the negative terminal of the battery, and hence will cross the junction and flow over into the base and toward the negative terminal of the battery. Here they will pick up an electron and disappear.

Thus we will have a current flow in the base-collector circuit due to the minority carriers. This is the same situation that we had in the reverse biased base-collector circuit of the PNP transistor.

Now let us see what happens when bias voltages are applied across both junctions of the complete NPN junction transistor as shown in Fig. 24. Considering first the emitter-base circuit, we have electrons flowing from the negative terminal of the battery to the N-type emitter. Here the electrons flow through the emitter, across the junction, and into the base. Some of these electrons reaching the base will recombine with holes in the base. This is called the recombination current. However, the majority of the electrons reaching the base will be attracted by the positive potential applied to the collector and hence will flow through the base across the base-collector junction and through the N-type collector to the positive terminal of the battery in the base-collector circuit.

At the same time the positive terminal of the battery in the emitter-base circuit is connected to the base, and this potential will pull electrons out of the P-type base, producing holes. These holes will then cross the junction into the emitter, and they will be attracted by the negative potential applied to the emitter and hence will flow through it to the end connected to the negative terminal of the battery. Here they will pick up an electron and disappear.

At the same time, in the base-collector circuit we will have a reverse current flowing due to the minority carriers. Holes appearing in the collector side of the depletion layer will cross the junction into the base and flow to the base terminal connected to the negative terminal of the battery, biasing the base-collector junction. Here each hole will pick up an electron and disappear. Electrons in the depletion layer on the base side of the junction will be attracted by the positive potential applied to the end of the collector. Hence they will cross the junction and flow toward the positive end of

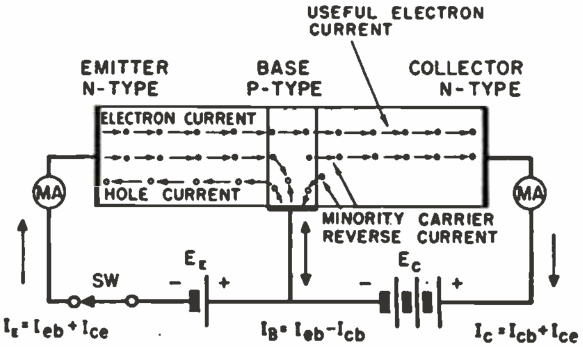


Fig. 24. Current flow and carrier movement in an NPN junction transistor.

the collector and from there to the positive terminal of the battery connected between the base and the collector.

Of these different currents flowing, the important and useful current flow is the flow of electrons from the emitter through the base to the collector. Since this is the useful current, we are interested in making this as large as possible in comparison to the other currents flowing across the emitter-base junction. Thus, the recombination current, which is due to electrons from the emitter crossing into the base and recombining with the holes, serves no useful purpose and should be kept as low as possible. This is accomplished by adding more donor atoms to the emitter than accepter atoms to the base. Thus there will be many more free electrons in the emitter than there will be holes in the base and the recombination current will be kept quite small.

Also, since there are a limited number of holes in the base compared to the number of electrons in the emitter, the number of holes crossing from the base to the emitter is also kept low in comparison to the number of electrons crossing from the emitter into the base. In a good transistor, over 95% of the electrons that cross the emitter-base junction flow to the collector.

Notice the differences and the similarities between the PNP and the NPN transistors. In both cases the emitter-base junction is forward biased and the base-collector junction is reverse biased. However, the battery connections must be reversed to provide the biases. In other words, with the PNP transistor the battery used to bias the emitter-base junction is connected with the positive terminal to the emitter and the negative terminal to the base. With the NPN transistor, the negative terminal of the battery is connected to the emitter and the positive terminal to the base. However, both are forward biased because in each case the positive terminal of the battery is connected to the P-type germanium and the negative terminal to the N-type germanium.

The base-collector junction of both transistors is reverse biased. In the PNP transistor, the positive terminal of this battery is connected to the base and the negative terminal to the collector; whereas in the NPN transistor, the negative terminal is connected to the base, and the positive terminal to the collector. Again, however, in both cases the positive terminal is connected to the N-type germanium and the negative terminal to the P-type germanium.

Also notice that in the PNP transistor the useful current flow is by means of holes, whereas in the NPN transistor the useful current flow is by means of electrons.

SELF-TEST QUESTIONS

(an) What is the base region of a transistor?

(ao) What two materials are widely used in the manufacture of transistors?

(ap) What two types of junction transistors are widely used?

(aq) What type of bias is used across the emitter-base junction in a transistor?

(ar) What type of bias is used across the base-collector junction of a transistor?

(as) Is the base region of a transistor usually a thick region or is it thin?

(at) Draw a diagram of a PNP transistor and show how the batteries are connected to place the correct bias across the two junctions.

(au) Draw a diagram of an NPN transistor and show how the batteries are connected to provide the correct bias across both junctions.

(av) What are the useful current carriers in a PNP transistor?

Semiconductor Types

There are two basic types of transistors that you will run into continuously. You are already familiar with these two types; they are the NPN transistor and the PNP transistor. However, these transistors are made in a number of different ways and the manufacturing processes result in transistors with different characteristics. In this section we are going to briefly discuss some of the important types and characteristics. We don't expect you to remember all these details; the important thing for you to remember is that they are basically either NPN or PNP transistors and operate in the same way as those we have discussed previously.

Also in this section of the lesson we'll discuss two other important semiconductor devices, the field-effect and unijunction transistors.

GROWN-JUNCTION TRANSISTORS

The first commercially available junction transistors were of the grown-junction type. This type of transistor is made from a rectangular bar cut from a germanium crystal that has been grown. Suitable impurities are added so that NPN regions such as those shown in Fig. 25 are formed. The base of the transistor is usually located midway between the two ends. Suitable contacts are then welded to the emitter, base and collector regions.

Of course, the actual bar of semiconductor material used is quite small. The emitter and the collector are considerably larger than the base; the base is kept as thin as possible and may have a thickness of less than .001".

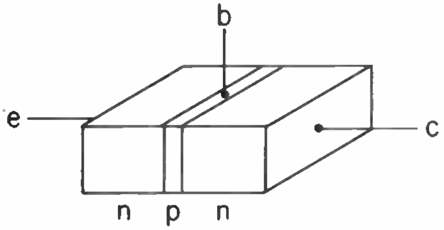


Fig. 25. A grown-junction transistor.

As mentioned the early germanium transistors were of the grown-junction type. The disadvantage of this type of transistor is that it is not particularly suitable for operations at high frequencies. In addition, it is quite temperature sensitive and can become quite unstable at higher temperatures.

ALLOY-JUNCTION TRANSISTORS

The alloy-junction transistor is made from a rectangular piece of

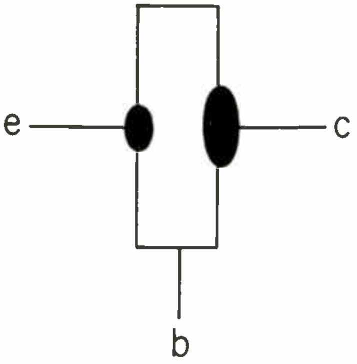


Fig. 26. An alloy-junction transistor.

semiconductor material to which suitable donor materials have been added. This results in an N-type piece of germanium or silicon. Small dots of indium are fused into the opposite sides of the wafer as shown in Fig. 26. The result is that P-type semiconductor material will be formed with the dots fused into the wafer so that we will have a PNP transistor.

An NPN-type alloy-junction transistor may be made by fusing a lead antimony alloy into each of the two opposite sides of a P-type semiconductor wafer. In this type of transistor it is possible to get a more uniform penetration of the lead antimony alloy into the semiconductor material, and this in turn leads to better junction spacing. This will cut down on the width of the space between the emitter and collector and give improved high-frequency performance. In addition, since the mobility of the electrons is more than twice that of holes, the NPN transistor will be better at high frequencies.

The general advantage of the alloy-type junction over the grown-type junction transistors is that they are usable at a somewhat higher frequency. In addition, they have a higher current gain, and the current gain remains stable as the temperature increases.

Surface-Barrier Transistor.

The surface-barrier transistor is similar to the alloy-type transistor except that depressions are etched into the N-type wafer. This permits smaller emitter and collector contacts and results in lower capacities between sections of the transistor which in turn results in better high-frequency performance.

In Fig. 27 we have shown a simplified sketch of a surface-barrier transistor. The sketch in Fig. 27B shows the carrier movement from the emitter across the base to the collector. Notice that in the sketch the emitter is shown smaller than the collector, we have shown it this way because this is the way the semiconductor is actually manufactured.

Various manufacturing techniques are used in the manufacture of the surface-barrier transistor. Both silicon and germanium types are made. In the manufacturing process different materials are evaporated or plated on to the etched depressions depending on the type of tran-

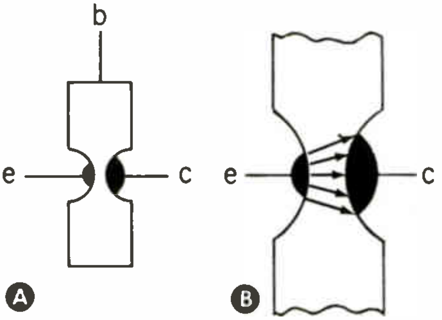


Fig. 27. Sketch of a surface barrier transistor is shown at A. Hole movement across the base is shown at B.

sistor being manufactured. However, regardless of the manufacturing technique used, which is of no interest to the technician, the surface-barrier transistors all have the characteristic of giving good performance at high frequencies.

DIFFUSION TRANSISTORS

To understand diffusion you have to understand a little about the molecular structure of materials. If you look at the wall of a glass jar, to the eye it appears solid with no space between the various molecules making up the jar. However, if you were to fill the jar with hydrogen and store it for any length of time, you would find that in a short while, the jar was no longer filled with hydrogen only, but contained a mixture of hydrogen and air. The reason is that the small hydrogen atoms are able to diffuse or pass right through the spaces between the molecules in the glass. At the same time, molecules of air will diffuse through the glass and pass on into the inside of the bottle. The hydrogen molecule is smaller than the air molecule; therefore the hydrogen will diffuse out of the jar faster than the air will diffuse in.

Diffusion can be used to add impurities to either silicon or germanium, and produce either N-type or P-type semiconductor material. The process can be controlled to provide either very uniform base, emitter, and collector regions, or it can be controlled to provide non-uniform base, emitter, and collector regions.

The Drift Type.

One of the most important uses of the diffusion technique is in the manufacture of transistors with a non-uniform base region. If the emitter and collector junctions are made by the alloy technique, but the base region is made by the diffusion technique and the impurities in the base region varied, we have what is known as a drift transistor. In a typical PNP-drift transistor, accepter impurities are added in the emitter and collector region. These impurities are controlled so that their concentration is uniform throughout the emitter and collector region. At the same time donor impurities are added to the base region. Their concentration is controlled so that it is highest in the region of the emitter-base junction and then drops off quickly and finally reaches a constant value which it maintains over to the base-collector junction, as shown in Fig. 28. This type of transistor is called a drift transistor, and its most important characteristic is its excellent performance at high frequencies. However, notice that it is still a PNP transistor and the basic theory of its operation is similar to that of any other PNP transistor. The improved performance is obtained by varying the concentration of donor impurities in the base region.

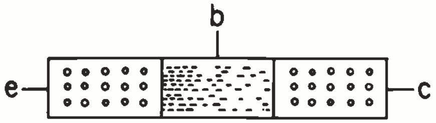


Fig. 28. Diagram showing how a large number of donor impurities increases the electron concentration in the base.

The Mesa Type.

It is also possible to manufacture a transistor using the diffusion technique entirely. An example of this type is the mesa transistor.

In this type of transistor a semiconductor wafer is etched down in steps so that the base and emitter regions appear as plateaus above the collector region as shown in Fig. 29. The advantages of the mesa transistor are good high-frequency performance and very good consistency. By this we mean that it is possible to control the manufacturing techniques quite closely so that the characteristics of mesa transistors of the same type number will be quite similar. This is not necessarily true of other transistors; often their characteristics vary over a wide range.

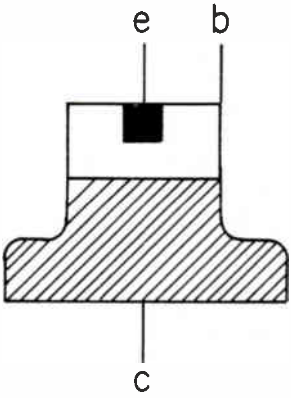


Fig. 29. A mesa transistor.

The Planar Type.

Another type of transistor manufactured by the diffusion technique is the planar type of diffused transistor. This type of transistor is shown in Fig. 30. Notice that each of the junctions is brought back to a common plane, whereas in the mesa type the various junctions are built up in plateaus. The importance of the planar-type transistor is that the junctions can be formed beneath a protective layer. As a result, many of the problems associated with other types of transistors having

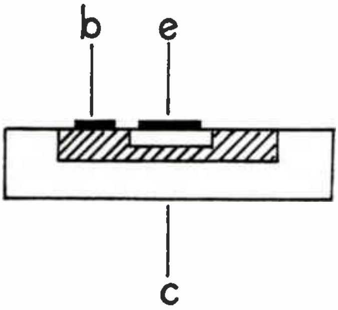


Fig. 30. A diffused planar-type transistor.

junctions exposed at the surface are avoided in this type of construction. Important characteristics of the planar transistor are generally very low reverse current and improved dc gain at low-current levels.

EPITAXIAL TRANSISTORS

One of the disadvantages of the diffusion-type transistor is the relatively high resistance of the collector region. This results in slow switching time; it limits the usefulness of the transistor in high-frequency applications. Reducing the resistance of the collector region reduces the collector breakdown voltage and this in turn again reduces the usefulness of the transistor. These problems can be overcome by the epitaxial technique. In this technique a thin high-resistance layer is produced in the collector region and the remainder of the collector region is controlled to keep its resistance low. This results in a transistor that looks something like the one shown in Fig. 31. The primary advantage of this transistor is that it provides good performance at very high frequencies. This technique can be combined with other techniques to produce transistors having varying characteristics. The epitaxial transistor can be referred to as a double-diffused epitaxial transistor. The thin high-resistance collector region is formed by the epitaxial technique and the base and the emitter are formed by the diffusion process - hence the term double diffusion.

All the transistors that we have discussed so far in this section of the lesson are either NPN or PNP transistors. The manufacturing techniques used to manufacture these transistors result in transistors of different characteristics, but the basic theory of operation of these transistors is the same. Now, we'll look at another semiconductor device which operates on a somewhat different principle.

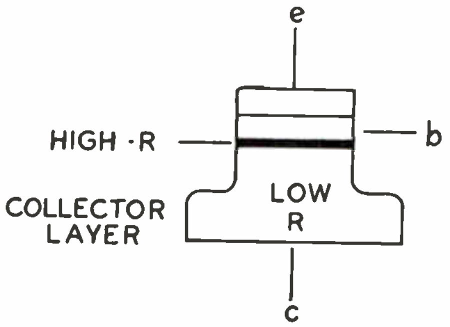


Fig. 31. A double-diffused epitaxial transistor.

THE JUNCTION FIELD-EFFECT TRANSISTOR

An interesting transistor that resembles a vacuum tube very closely in its characteristics and to some extent its operation is a field-effect transistor. One type of field-effect transistor can be made by taking a piece of N-type material as shown in Fig. 32. If the negative terminal of a battery is connected to one end of the material and the positive side of the terminal to the other end, electrons will flow through the material as shown. If we attach a piece of P-type material to one side so that the PN junction is formed and then place a negative voltage on the P-type material as shown in Fig. 32, there will be no current flow across the junction, because the battery biases the junction in such a way that electrons cannot flow from the N-type material to the P-type material nor can holes flow from the P-type material to the N-type.

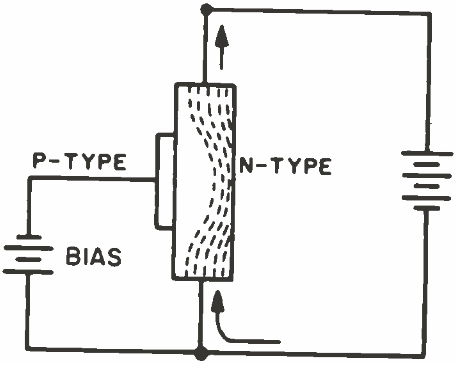


Fig. 32. Drawing showing the basic operation of a field-effect transistor.

However, the negative voltage applied to the P-type material sets up a field in the N-type material. This field opposes the electrons flowing through the N-type material and forces them to move over to one side so that the electron movement follows the path shown in Fig. 32. The negative voltage applied to the P-type material has the effect of increasing the resistance of the N-type material in the area in which the field is affected. It forms a depletion layer around the junction so there will be no free electrons in the N-type material near the junction. If the negative bias voltage is made high enough, it is able to prevent

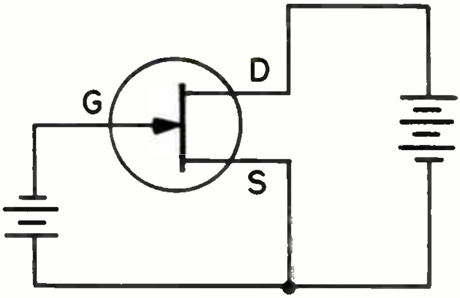


Fig. 33. Schematic representation of the circuit shown in Fig. 32.

the flow of electrons through the N-type material entirely so that the current flow will be cut off. We call this voltage where the bias voltage is high enough to stop the flow of current through the N-type material the "pinch-off" voltage. The N-type material is referred to as a channel, and the P-type material as a gate. This type of transistor is called a "junction field-effect transistor."

The schematic representation of the circuit shown in Fig. 32 is shown in Fig. 33. Notice that the end of the N-type channel at which the electrons from the battery enter is called the "source". The other end, the end from which the electrons leave and flow to the positive terminal of the battery, is called the "drain". The P-type material is called the gate, as we mentioned previously. The transistor is called a field-effect transistor because it is the field produced by the bias voltage applied to the gate that controls the flow of current through the channel. This particular type of transistor is called a junction transistor because a junction is formed between the P and N-type materials. It is called an N-channel transistor because the material in the channel through which current flows has been treated in such a way as to produce an N-type semiconductor material. Thus the complete name for this type of transistor is an N-channel, junction-gate, field-effect transistor. We usually abbreviate field-effect transistor FET, so you will see that this type of transistor is abbreviated JFET to indicate it is a junction-gate type.

An amplifier using a field-effect transistor of this type is shown in Fig. 34. In this circuit we have eliminated the bias battery by means of a resistor connected between the negative terminal of the battery and the source. This resistor might be compared to the cathode-bias re-

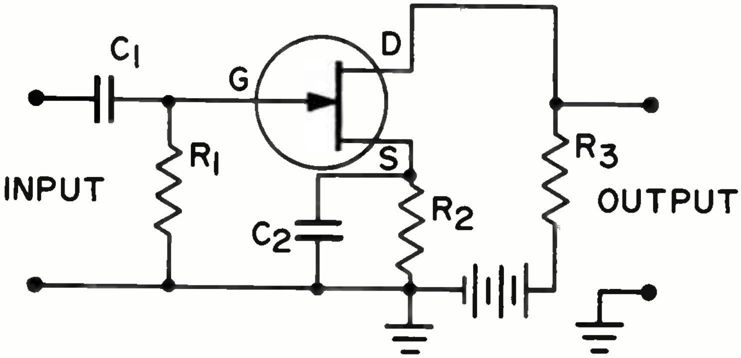


Fig. 34. An amplifier using an N-channel junction gate FET.

sistor in a triode vacuum tube amplifier stage. In the amplifier circuit, electrons flow from the negative terminal of the battery through the resistor R_2 to the source. In so doing they set up a voltage drop across R_2 having a polarity such that the source is positive with respect to ground. Since the gate connects back to ground through R_1, the gate will be at ground potential and this will make the source positive with respect to the gate, or in other words, the gate negative with respect to the source. Therefore none of the electrons in the N channel will flow to the gate, because the gate is negative.

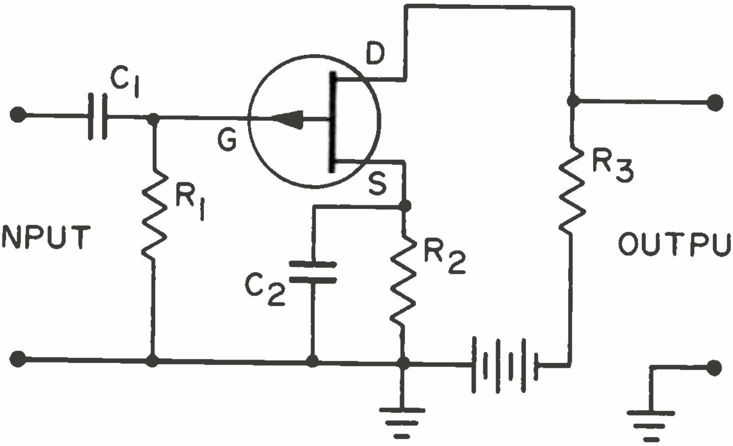


Fig. 35. An amplifier using a P-channel junction gate FET.

Electrons will flow through the N channel to the drain and then through the load resistor R_3 back to the positive terminal of the battery. As the input voltage applied across the input terminals causes the voltage between the gate and the source to vary, the current flow from the source to the drain will vary because the controlling action of the gate on the current through the channel depends upon the voltage between the gate and the source. Thus we have a varying current, which will vary as the input signal varies, flowing from the source to the drain of the transistor and through the load resistor R_3. This varying current flowing through R_3 will produce an amplified signal voltage across R_3.

It is interesting to note the similarity between the circuit shown in Fig. 34 and a triode amplifier. When the input signal swings the gate in a positive direction, current flowing through the transistor will increase; this will cause the voltage drop across R_3 to increase and therefore the voltage between the drain and ground will decrease. Thus a positive-going signal applied to the gate will cause a negative-going signal at the drain. In other words, this transistor inverts the signal phase just as the triode vacuum tube amplifier stage does.

P-Channel JFET.

It is possible to make a P-channel junction-gate field-effect transistor by using a P-type material between the source and drain. The gate is then made of an N-type material. The bias polarity is reversed so that once again the PN junction is biased and no current flows across the junction.

A schematic diagram of an amplifier using a P-channel junction-gate effect is shown in Fig. 35. Notice the schematic symbol for the P-channel unit; we have turned the direction of the arrow around just as we did to distinguish between NPN and PNP transistors. Also notice that in this circuit the battery polarity is reversed. This is because the carriers in the channel in the P-channel unit will be holes. The positive terminal of the battery which connects to the source through R_2 repels the holes and they travel through the channel to the drain where they are attracted by the negative potential connected to the drain. Meanwhile, holes arriving at the drain terminal are filled by electrons which flow from the negative terminal of the battery through R_3 to the drain. At the same time, the positive terminal of the battery attracts electrons from the source creating new holes. These electrons flow from the source through R_2 to the positive terminal of the battery.

The operation of the P-channel, junction-gate effect is the same as with the N-channel unit, except that in one case the majority carriers are electrons, and in the other case they are holes.

In discussing the action of the junction-gate field-effect transistor, we often refer to the reverse bias across the junction creating a depletion layer in the conducting channel. In the case of an N-channel unit, the negative voltage on the P-type gate will repel electrons at the junction so that the electrons have been depleted from that area around the junction. The higher the negative voltage the further the electrons are depleted in the area around the junction, and as we pointed out previously if the voltage is made high enough, all of the electrons will be depleted so that there will be no current flow through the channel. The transistor is referred to as a depletion-type transistor because the bias depletes the number of majority carriers from the channel around the junction region. Remember what we mean by a depletion type of FET; you'll see later there is another type.

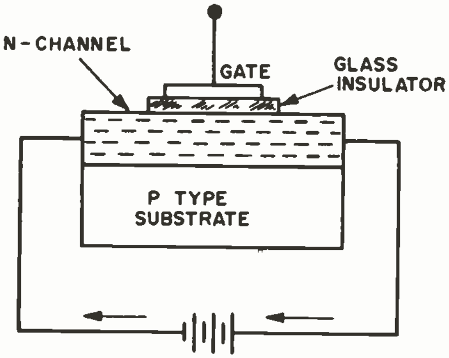


Fig. 36. Current flow through an insulated-gate, N-channel field-effect transistor with no bias applied.

INSULATED-GATE FIELD-EFFECT TRANSISTORS

The transistors we have been discussing so far are called junction-gate field-effect transistors. There is another type of field-effect transistor that is called an insulated-gate field-effect transistor. We usually abbreviate this IGFET.

In the insulated-gate field-effect transistor, the gate is completely insulated from the channel by a thin insulating material. For example, a very thin piece of glass might be placed between the conducting channel and the gate. Thus there is no actual junction formed between the semiconductor materials in the channel and the gate. In an N-channel, insulated-gate field-effect transistor, construction such as shown in Fig. 36 is often used. Here we have an N channel between the source and drain. The substrate on which the channel material is mounted is P-type material and the gate is placed along the channel as shown in the figure. The thin layer of glass prevents any actual contact between the channel and the gate.

In operation, the source and the substrate are connected to the negative terminal of the battery and the drain is connected to the positive terminal. This will permit current to flow from the negative terminal of the battery to the source, through the channel to the drain and then back to the positive terminal of the battery.

When a negative voltage is applied to the gate, it has the effect of repelling electrons away from the gate as before. In addition, the negative potential applied to the gate attracts holes in the P-type material so that the width of the channel is reduced as shown in Fig. 37. Thus the current flow through the channel is restricted by the narrowing of the channel. In effect, the resistance of the channel is increased. We refer to this type of channel as a depletion channel. The transistor is called an insulated-gate-field-effect transistor and it is also referred to as a depletion type because the flow of current through the transistor is controlled by producing a depletion layer in the channel as in the case of the junction transistors discussed previously.

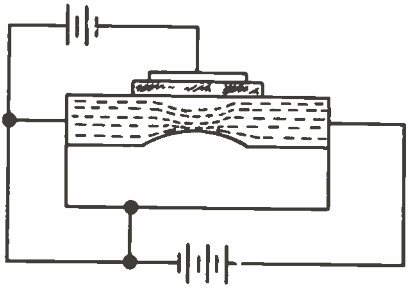


Fig. 37. Current flow through an N-channel IGFET with bias applied.

Both N-channel and P-channel IGFET's are manufactured. The schematic symbols used to represent the two different types are shown in Fig. 38A and B. In A, we have shown the symbol used for an N-channel type, and in B the schematic symbol used for a P-channel type. In operation, the units perform in essentially the same way as the junction-gate units with the exception that there will be no current

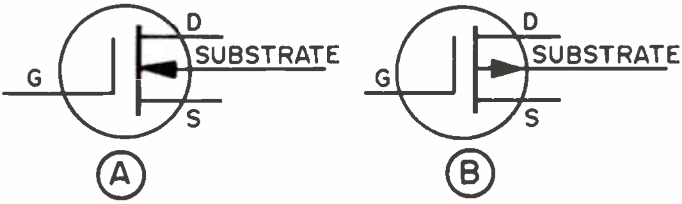


Fig. 38. Insulated-gate field-effect transistors. (A) shows the schematic symbol for an N-channel unit and (B) the symbol for a P-channel unit.

flow at all from the channel to the gate or from the gate to the channel. In the JFET, there may be very small leakage current across the junction. However, a JFET has a high input resistance because this leakage current is low. The IGFET has an even higher input resistance because there is no current flow at all from the gate to the channel or from the channel to the gate. Thus the input resistance of an IGFET is almost infinite.

Enhancement Type.

So far the field-effect transistors we have been discussing are all what are known as depletion types. In the depletion type of FET, the channel is formed and a bias is placed on the gate so as to reduce the size or width of the channel. In the enhancement-type of field-effect transistor, there is no channel present until the bias is applied to the gate. Thus, there is no current flow from the source to the drain through the transistor, unless there is a bias applied to the gate. The polarity of the bias applied to the gate is reversed from what it is in the depletion type, and this bias forms the channel through which current can flow. The operation of the units is the same as with the depletion type with the single exception of the reverse bias. In other words, in the case of an N-channel enhancement-type field-effect transistor, instead of placing a negative bias on the gate to reduce the width of the channel, as we do in the depletion-type transistor, in the enhancement-type we place a positive bias on the gate and produce the N channel.

The enhancement-type field-effect transistor is always an insulated gate type. In the case of a junction FET, if we produced an enhancement type, we would have current flow across the junction because the voltage required to produce the channel would forward bias the junction. However, in the insulated-gate FET, no current can flow across the junction because we have an insulating material between the gate and the channel. Thus we can put any type of bias we want, either forward or reverse bias, on the gate and we still will not get a current flow from the gate to the channel or from the channel to the gate.

The schematic symbol of an N-type IGFET of the enhancement type is shown in Fig. 39A. Notice that we have indicated there is no channel by breaking the channel into three parts. When the correct bias is applied to the gate, an N channel between the source and the drain will be formed. The schematic symbol for the P-channel unit of an enhancement-type IGFET is shown in Fig. 39B.

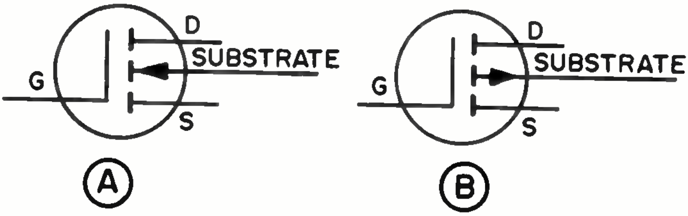


Fig. 39. A shows the schematic symbol for an N-channel enhancement-type IGFET. B shows the P-channel unit.

The operation of the enhancement-type IGFET is basically the same as with the depletion type. It could be used in a circuit similar to the circuits shown in Fig. 34 and Fig. 35.

One of the problems with IGFET's is the very high resistance between the gate and the channel. In shipping these units the manufacturer usually wraps the leads in tin foil to keep them connected together. If he doesn't do this, static charges can build up on the gate because of the very high resistance between the gate and the channel. These static charges may become high enough to actually puncture the insulation between the gate and the channel and thus ruin the unit.

In soldering an IGFET into a circuit, there might be enough leakage from the power line through the tip of your soldering iron to ruin the FET. To prevent this from happening, ground leads should be used on the various connections to the transistor and these leads should be left in place until the transistor is installed in the circuit. Once the transistor is soldered in place, you do not have to be concerned about static charges destroying the unit because the resistance in the circuit will be low enough to prevent static charges from building up to a high enough value to destroy the transistor.

Field-effect transistors are finding their way into commercial equipment, and you should therefore be sure you understand how they operate. You should review the sections on field-effect transistors several times if necessary because you can be sure they are going to be widely used in the future. They offer the advantages of the transistor as well as many of the advantages of the vacuum tube.

THE UNIJUNCTION

Another important semiconductor device is the unijunction. The unijunction is different from a conventional two-junction transistor in that it has only a single junction.

Most unijunctions are made of a bar of N-type silicon. There are two base contacts made to this bar called base 1 and base 2. These contacts are made at the ends of the bar. Between the two bases is a single rectifying contact called the emitter. The schematic symbol of the unijunction is shown in Fig. 40.

In Fig. 41 we have an equivalent circuit showing how the unijunction operates. We have referred to the resistance between base 1 and the emitter as R_{B1} and the resistance between base 2 and the emitter contact as R_{B2}. When a dc voltage is applied to the unijunction between B_1 and B_2, a current will flow through the base as shown. As long as the voltage drop across R_{B1} is greater than the emitter voltage, the emitter will be reverse biased so that there will be no current flow across the junction between the emitter and the base. The voltage across the resistance representing base 1 and the voltage across the resistance representing base 2 will remain constant. The two bases more or less act like two resistors

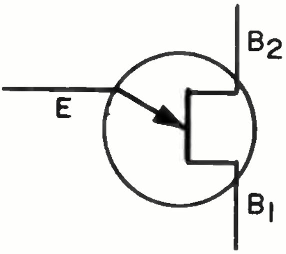


Fig. 40. Schematic symbol of a unijunction.

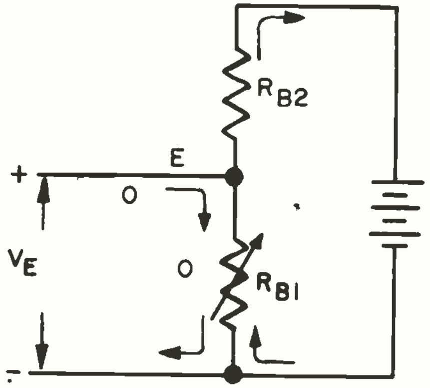


Fig. 41. Equivalent circuit showing the operation of the unijunction.

in series. The positive voltage at the emitter junction prevents any electrons from leaving the base and crossing the junction to the emitter and also prevents holes from traveling from the emitter to the base. There will be a small leakage current across the junction, but this is of no importance insofar as the operation of the unijunction is concerned.

If the voltage, V_E, exceeds the voltage across R_{B1}, then holes will enter the base and flow through R_{B1} as shown by the arrows on the diagram. These holes will cause the number of electrons flowing in R_{B1} to increase. The net result will be that you will have a drop in voltage across R_{B1} but at the same time an increase in current.

You will remember from Ohm's Law that the current flowing in a circuit is equal to the voltage divided by the resistance. If the voltage drops, the current must drop. However, in this device we have a situation where the voltage drops, but the current increases. We refer to this as "negative resistance". Devices that have this characteristic can be used in various types of amplifier circuits.

The unijunctions made for a number of years always made use of an N-type base material and a P-type emitter. However, recently some unijunctions using a P-type base material and an N-type emitter have been developed. The schematic symbol is the same, except that the direction of the arrow is reversed.

Unijunctions have not been widely used in commercial radio and TV equipment; however, they have been used in various pieces of test equipment. It is quite likely that as more transistorized television receivers are manufactured, the unijunction may be used in the sweep circuits since they are quite readily adapted to this type of application.

The important thing for you to remember at this time about the unijunction is that the device has a single junction and that the resistance of the two bases remains essentially constant until the emitter voltage exceeds the voltage across base 1. Then the voltage drop across base 1 decreases while the current flow through it increases, resulting in the negative resistance characteristic of base 1.

SUMMARY

There are too many details in this section to try to summarize them. The important thing for you to do is to realize that the different names assigned to the conventional two-junction transistors indicate the manufacturing process used to make the transistor. Typical two-junction transistors are either NPN or PNP transistors, and the basic theory of operation of the two-junction transistors is the same regardless of the manufacturing technique used. Different manufacturing techniques result in transistors with different characteristics, but the theory of operation is the same.

The field-effect transistor is a transistor that very closely resembles a vacuum tube in many of its characteristics. Remember that there are two basic types: the junction field-effect transistor and the insulated-gate field-effect transistor. In the insulated-gate type, the gate is insulated so that the leakage current to and from the gate is practically zero. This type of transistor has a very high input resistance.

You should also remember that field-effect transistors can be made in both N-channel types and P-channel types. You'll recall that by depletion type we are referring to a transistor where a channel is present. The input voltage to this type of transistor controls its channel width. JFET transistors are all of the depletion type. The IGFET may be either the depletion type or the enhancement type.

The unijunction is a semiconductor device with a single junction. Its use in commercial equipment is somewhat limited at this time, but you should understand the basic fundamentals of the device because it is quite likely that it will be used in the future.

One important point about all types of transistors that we must emphasize is that they are all easily damaged by excessive heat. This is true particularly of germanium transistors, but silicon transistors can also be destroyed by excessive heat. Whenever you have to replace a transistor in a circuit, you should make sure that the point at which you have to solder the transistor in the circuit is clean so that the solder will melt and flow over the connection quickly. Also make sure that the transistor leads are clean. It is a good idea to use a heat sink between the point at which you are soldering and the semiconductor device. A good heat sink is a pair of longnose pliers; simply hold the lead securely in the jaws of the pliers while you are soldering the lead in place. Much of the heat developed at the joint will flow through the pliers and keep the semiconductor device itself from becoming excessively hot. The joint should be soldered as quickly as possible; get the iron off the joint just as soon as the solder has melted and flowed smoothly over the connection.

Semiconductor devices can be damaged by storing them in excessively warm places. Again, this is particularly true of germanium transistors which are more heat sensitive than silicon transistors. Storing semiconductor devices at room temperature will prevent this type of damage. You should avoid storing them in any place where they can become excessively hot.

Now to check yourself on this important section you should answer the following self-test questions.

SELF-TEST QUESTIONS

(aw) Into what two basic types can the grown-junction transistor be divided?

(ax) What type of transistor can the surface-barrier transistor be classified as?

(ay) What is the most important characteristic of the surface-barrier transistor?

(az) What do we mean by a diffussion transistor?

(ba) What is an important use of the diffusion technique in manufacturing transistors?

(bb) What is the difference between a junction-gate field-effect transistor and an insulated-gate field-effect transistor?

(bc) What is a depletion-type field-effect transistor?

(bd) What is an enhancement-type FET?

(be) What is a unijunction?

Answers to Self-Test Questions

(a) Four.

(b) Germanium and silicon.

(c) A covalent bond is the sharing of two electrons by two atoms, one from each of the two atoms.

(d) Four. A single atom of germanium or silicon will share an electron from its outer ring and an electron from the outer ring of a nearby atom to form a covalent bond. It will do this with four electrons to establish four covalent bonds.

(e) Intrinsic conduction is conduction due to the formation of hole-electron pairs throughout a germanium or silicon crystal.

(f) No.

(g) Germanium.

(h) Heat.

(i) Silicon.

(j) An N-type material is a material that has been doped so that electrons are the majority carriers. This is brought about by using an impurity that has five electrons in the valence ring so that when it forms covalent bonds with nearby germanium or silicon atoms there will be an electron left over.

(k) A donor material is an impurity which when added to silicon or germanium will form covalent bonds with four nearby atoms and have an electron left over. When a donor material is added to germanium or silicon, N-type material is formed.

(l) Arsenic and antimony.

(m) P-type semiconductor material is a material that has been doped with an impurity having three electrons in the valence ring. This will leave a covalent bond that is short one electron so there will be a hole in the bond. The hole is in effect a positive charge and hence the majority carriers in the P-type material are the holes or positive charges.

(n) An accepter-type impurity is an impurity with three electrons in the valence ring or shell. It is an accepter-type material because it leaves a hole in the covalent bond which can accept an electron.

(o) Indium, boron and aluminum.

(p) Electrons are the majority carriers in N-type material.

(q) Holes.

(r) When the arsenic loses an electron it will be short one electron to completely neutralize the charge on the nucleus, and therefore the atom will have a positive charge. Meanwhile the atom of silicon or germanium that has received the extra electron will have a negative charge on it.

(s) There is no charge on the crystal, it is neutral. Although some regions may have a positive charge, other regions may have a negative charge; the crystal itself neither gains nor loses electrons and therefore it does not have any charge.

(t) Holes are produced.

(u) Diffusion is a random motion of the carriers in a semiconductor material. It goes on at all times in the crystal and every effort is made to keep diffusion as low as possible since it contributes nothing insofar as the usefulness of the material in semiconductor devices is concerned.

(v) Drift.

(w) Electrons are the majority carriers in an N-type material and they move from the end to which the negative potential is applied towards the end to which the positive potential is applied.

(x) Holes are the majority carriers in a P-type material and they move from the end to which the positive potential is applied to the end to which the negative potential is applied.

(y) No - the crystal will remain electrically neutral. In the case of N-type material, exactly the same number of electrons will leave the positive end of the crystal and enter the negative end of the crystal. In the case of the P-type material, electrons will leave the end to which the positive potential is connected creating holes. Exactly the same number of electrons will enter the end to which the negative potential is connected to fill holes arriving at the negative end.

(z) No. For a given potential and given size of crystal, electrons will move at approximately twice the rate through an N-type crystal as the holes will through a P-type crystal.

(aa) The N-type material will have the lower resistance. This is due to the higher mobility of the electrons in the N-type material than the holes in the P-type material.

(ab) Detectors and rectifiers.

(ac) The depletion layer is an area on both sides of the junction. On the P-side of the junction there is a shortage of holes and on the N-side of the junction there is a shortage of electrons. The shortage is caused by a few of the majority carriers crossing the junction in each way building up a charge at the junction so that the majority carriers are repelled away from the junction.

(ad) The potential barrier is the voltage built up across the junction by the diffusion of majority carriers across the junction. The holes that diffuse across the junction into the N-side of the junction create an area that has a negative charge in the P-side of the junction. Similarly, the electrons diffusing across the junction into the P-side create an area on the N-side of the junction that has a positive charge. This charge across the junction eventually becomes high enough to prevent any further diffusion of holes and electrons across the junction.

(ae) No. The net charge on the crystal will remain zero. There may be areas on the crystal that have a positive charge, and other areas that have a negative charge, but since the crystal itself neither gains nor loses electrons, the net charge on the crystal will remain zero.

(af) Yes. Minority carriers crossing the junction tend to weaken the potential barrier established across the junction by majority carriers diffusing across the junction. When the potential barrier is weakened, additional majority carriers can cross the junction. Thus we end up with carriers crossing the junction in both directions. This adds nothing to the useful current that the diode can handle, but it does contribute to heating and thus limits the useful current that can cross the junction.

(ag) When a junction is forward biased we have a positive potential applied to the P-side and a negative potential applied to the N-side. This permits electrons to freely cross the junction from the N region to the P region. Similarly holes can cross the junction from the P region to the N region.

(ah) When a junction is reverse biased we have a negative potential connected to the P region and a positive potential connected to the N region. The positive potential connected to the N region repels holes in the P region away from the junction so that they cannot cross the junction. Similarly, the negative potential applied to the P region repels electrons in the N region away from the junction so that they cannot cross the junction. When a junction is reverse biased, majority carriers normally cannot cross the junction.

(ai) When there is no voltage applied to a semiconductor diode, the net current flow across the junction is zero. However, in the case of a vacuum tube where there is no voltage applied between plate and cathode, some electrons will leave the cathode with sufficient energy to travel over to the plate. As a result, there will be a small current through the diode even though there is no voltage applied between the plate and cathode.

(aj) When a semiconductor diode is reverse biased, there will be a small current flow across the junction due to minority carriers. As long as the breakdown voltage of the diode is not exceeded, this current will be quite small. In the case of a vacuum tube, when the plate is made negative with respect to the cathode, the plate will repel electrons so that there will be no current flow through the vacuum tube.

(ak) A Zener diode is a diode used in applications where a reverse bias is placed across the junction. The diode is designed to break down at a certain voltage and then maintain a constant voltage. If the voltage tries to increase above this constant value, the current flow through the Zener diode will increase so that the diode can be used in voltage regulating circuits and also can be used as a voltage reference source.

(al) A tunnel diode is a diode where the electrons cross the junction by a process similar to tunneling across the junction. The tunnel diode has a characteristic of introducing negative resistance into the circuit when a certain voltage is applied across the junction. In other words, when the voltage across the diode increases, the current flow through the diode decreases. Similarly, when the voltage decreases the current increases. Because of this negative resistance characteristic, the tunnel diode can be used as an oscillator.

(am) A p-i-n diode is a diode that is primarily used as a variable resistance. The resistance of the diode varies as the voltage across it is varied. The p-i-n diode is used in automatic gain control circuits to vary the strength of the signal reaching amplifier stages.

(an) The base region is the center region of the transistor. On one side of the base region is the emitter, and on the other side is the collector.

(ao) Germanium and silicon.

(ap) PNP transistors and NPN transistors.

(aq) Forward bias.

(ar) Reverse bias.

(as) The base region is usually comparatively thin.

(at) See Fig. 22.

(au) See Fig. 24.

(av) Holes are useful current carriers in a PNP transistor.

(aw) NPN and PNP transistors.

(ax) An alloy-type transistor.

(ay) Good high-frequency performance.

(az) A diffusion transistor is a transistor which has been made by diffusing the impurities into the emitter, base and collector regions.

(ba) One of the most important uses of the diffusion technique is in the manufacture of non-uniform base regions.

(bb) In a junction-gate field-effect transistor there is an actual contact between the channel material and the gate. There will be some current flow across the contact at all times due to minority carriers crossing the junction. In addition, if the junction is forward biased there will be a high current flow across the junction. In an insulated-gate field-effect transistor a glass or similar insulating material is used between the material in the channel and the gate. Since there is an insulator between the gate and the channel, there will be little or no current flow across the insulator either due to minority carriers when there is a reverse bias applied, or due to majority carriers with a forward bias applied.

(bc) A depletion-type FET is a unit in which the channel is present at all times. The transistor works by depleting or reducing the size of the channel.

(bd) An enhancement FET is a unit in which there is no channel present until the operating bias is applied between the gate and the material in which the channel is formed.

(be) A unijunction is a semiconductor device having two base connections but only a single junction. The junction is called the emitter. The single junction makes the unijunction quite different from the conventional two-junction transistor.

LESSON QUESTIONS

Be sure to number your Answer Sheet B112.

Place your Student Number on every Answer Sheet.

Most students want to know their grades as soon as possible, so they mail in their answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable. However, don't hold your answers too long; you may lose them. Don't hold answers to more than two sets of lessons at any time, or you may run out of lessons before new ones can reach you.

1. Name the two most important semiconductor materials used for transistors.

2. When a donor type of material is added to a silicon or a germanium crystal, what type of semiconductor material is produced? Does this type have free electrons or free holes?

3. What effect do the two layers of ionized atoms at the junction in a PN diode have on the majority carriers in the vicinity of the junction?

4. To which side of a PN junction diode do you connect the positive battery terminal if you wish to place a forward bias on the junction?

5. If a reverse bias is applied to a junction diode, what effect will a small increase in bias have on the current flowing, provided the reverse voltage does not exceed the breakdown voltage?

6. What is a Zener diode?

7. In a PNP transistor, what happens to a hole that crosses the emitter and the base and moves into the collector?

8. What is a drift transistor?

9. What is an N-channel, junction-type field-effect transistor?

10. What do we mean when we refer to a field-effect transistor as an enhancement type?

CASHING IN ON DISCONTENT

Discontent is a good thing--if it makes you want to do something worthwhile. If you had not been discontented, you would never have enrolled for the NRI course.

Practically everyone is discontented. But some of us are "floored" by discontent. We develop into complainers. We find fault with anything and everything. We end up as sour and dismal failures.

Those of us who are wise use our discontent as fuel for endeavor. We keep striving toward a goal we have set for ourselves. We are happy in our work. We face defeat, and we come out the victors.

At this minute you may be discontented with many things--your progress with your course, your earning ability, yourself.

Make that discontent pay you dividends. Don't let it throw you down. If you do, you may never be able to get up again. Keep striving to remove the cause of your discontent. Remember that it's always darkest before the dawn. And a real NRI man works hardest and accomplishes most when he is face to face with the greatest discouragements.

J. M. Smith


nri

ACHIEVEMENT THROUGH ELECTRONICS

HOW TRANSISTORS ARE USED

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STUDY SCHEDULE

By dividing your study into the steps given below, you can get the most out of this part of your NRI Course in the shortest possible time. Check off each step when you finish it.

☐ 1. **Introduction** . . . . **Pages 1 - 3**

This gives a brief discussion of the advantages and disadvantages of transistors compared to vacuum tubes, and a look at the basic circuits you will study.

☐ 2. **The Common-Base Circuit** . . . . **Pages 4 - 9**

The common-base circuit for both NPN and PNP transistors is discussed.

☐ 3. **The Common-Emitter Circuit** . . . . **Pages 10 - 15**

The common-emitter circuit is the most frequently used transistor circuit. You learn about both NPN and PNP common-emitter circuits.

☐ 4. **The Common-Collector Circuit** . . . . **Pages 16 - 21**

You study both NPN and PNP common-collector circuits.

☐ 5. **Transistor Characteristics** . . . . **Pages 22 - 28**

You study characteristic curves and various transistor characteristics.

☐ 6. **Typical Transistor Circuits** . . . . **Pages 29 - 37**

You learn how basic transistor circuits are modified to be used as audio and rf amplifiers.

☐ 7. **A Typical Transistor Receiver** . . . . **Pages 38 - 41**

We take a complete schematic diagram of a radio receiver using transistors and see how the stages you have studied are used together.

☐ 8. **Answers to Self-Test Questions** . . . . **Pages 41 - 44**

☐ 9. **Answer the Lesson Questions.**

☐ 10. **Start Studying the Next Lesson.**

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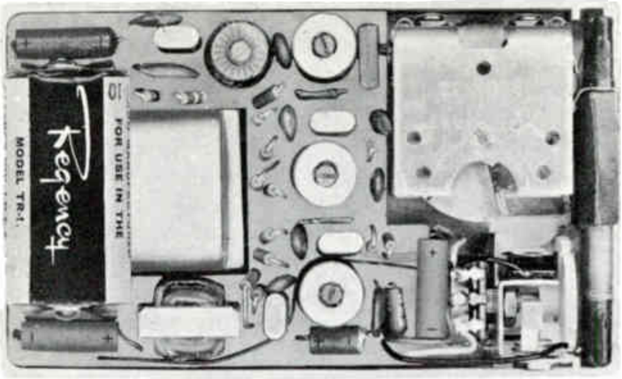


HOW TRANSISTORS ARE USED

Just a few years ago a germanium transistor cost considerably more than most vacuum tubes, and the cost of silicon transistors was many times that of germanium transistors. Silicon transistors were priced so high that their use in commercial entertainment devices was prohibitive. Even germanium transistors were priced so high that it was hard to justify their use in entertainment-type equipment. Now, however, both germanium and silicon transistors are relatively inexpensive. There are many transistors of both types priced lower than even the most inexpensive vacuum tubes. For this reason they are widely used in commercial equipment. All portable radio receivers manufactured today use transistors. You will not run into a portable receiver using tubes except in the case of a receiver that is many years old. Automobile radios use transistors, and most stereo and hi-fi equipment is made entirely with solid-state devices. There are many portable television receivers on the market and in use today that use transistors exclusively. In addition, there are hybrid receivers that use both tubes and transistors.

TRANSISTORS AND TUBES

A transistor can do almost anything a vacuum tube can do. Sometimes a transistor can perform a task better than a vacuum tube; sometimes it cannot perform the task as well as a vacuum tube.

Advantages of Tubes.

The big advantage vacuum tubes have over transistors is that it is usually possible to obtain a higher gain with a single vacuum tube than it is with a single transistor. In addition, a number of tubes can be combined in a single envelope so that a single vacuum tube may actually contain three or more separate tubes in the same envelope. This often results in the multi-purpose tube being more economical than the equivalent number of transistors that would be required to perform the same functions.

Another advantage of the tube is that today's engineers are more used to working with them. Thus the cost of designing a piece of electronic equipment, such as a color TV receiver, using tubes is less than the cost of designing a color TV receiver using transistors.

The characteristics of tubes are more uniform than those of transistors. In other words, it is easier to duplicate circuits using tubes than circuits using transistors. Furthermore, when it comes time to replace a transistor, you may find the replacement has quite different characteristics from the original and that the stage will perform quite differently from the manner in which it did with the original transistor. You are not likely to run into this situation with a tube.

Advantages of Transistors.

To offset the advantages of the vacuum tube, the transistor offers many other advantages. Generally speaking, a transistor for a particular job is smaller than a vacuum tube. The transistor is more rugged than the vacuum tube and there is less chance of it breaking. A transistor does not require any power to heat a cathode or filament - this reduces the power requirement of the equipment and also reduces the amount of heat that must be dissipated by the equipment. The lower temperature inside the equipment generally results in longer life from all the other parts in the equipment.

Transistors operate on lower voltages than vacuum tubes. This often results in savings in the power supply and also in the voltage ratings of the other components in the circuit.

BASIC TRANSISTOR CIRCUITS

In the span of the few short years in which transistors have been manufactured for commercial applications, there have been a large number of different transistor types manufactured. Each year manufacturers introduce new types, and we can expect that this will continue year after year. This might make you think that it will be an almost impossible job to keep up with new developments in the field of transistors. However, this is not the case. Like tubes, transistors are used in certain basic circuits. If you learn these basic circuits and how they work, you should be able to understand new circuits as you encounter them. In addition, there are certain basic characteristics of transistors that are important. Once you learn what these characteristics are and what they mean, you will be in a position to evaluate new transistors as they appear on the market in comparison with older transistors with which you may be more familiar.

As you will remember from your study of vacuum tubes, the triode tube has three elements: a cathode, a plate and a grid. You will remember that we found that there are three different types of circuits in which a triode tube can be used: the grounded-cathode circuit, the grounded-plate circuit, and the grounded-grid circuit. Similarly, a triode transistor has three elements: an emitter, a base, and a collector. There are three basic circuits in which a triode transistor can be used. These circuits are called the common-base circuit, the common-emitter circuit, and the common-collector circuit. In transistor circuits we usually use the word "common" when speaking of different circuits, but actually a common-base circuit is a grounded-base circuit--in other words a circuit where the base is at the ac ground potential.

Now let's study the three basic circuits to learn something about the important characteristics of each type. It is important for you to understand these three circuits. If you understand them you should have no difficulty with the other circuits you encounter in this book because they will all be variations of one of these three circuits.

Of the three circuit variations in which a triode transistor may be used, the common-emitter circuit is found more frequently than the other two. This is the circuit that will give the greatest voltage and power gain. However, we will start our study of the three circuits with the common-base because you have already seen the circuit in the preceding lesson and also because it is a little easier to understand than the other two circuits.

In studying these three basic circuits we will compare their characteristics with the three basic vacuum-tube circuits. You will see a great deal of similarity between the three circuits insofar as performance is concerned, but you will also see some very noticeable differences. You should keep in mind that, although the end results may be the same, there is a great deal of difference between the way a circuit using a vacuum tube and one using a transistor works.

The Common-Base Circuit

Typical common-base circuits are shown in Fig. 1. The circuit shown at A is for an NPN transistor; the circuit shown at B is for a PNP transistor.

The solid arrows on the two diagrams indicate the direction of useful electron flow. In the circuit shown at A, electrons flow from the negative terminal of battery B1, through resistor R1, through the NPN transistor, into the emitter, across the emitter-base junction to the base, then across the base-collector junction into the collector, and from the collector through the collector resistor R_C to the positive terminal of battery B2. Notice that the emitter-base junction is forward biased, and the base-collector junction is reverse biased as in all transistor circuits.

In the circuit shown in Fig. 1B, the batteries are reversed. Since this is a PNP transistor, in order to place a forward bias on the emitter-base junction, the positive terminal of the battery must be connected to the emitter and the negative terminal to the base; similarly, battery B2 is reversed because, to place a reverse bias on the base-collector junction, the negative terminal must be connected to the collector and the positive terminal to the base.

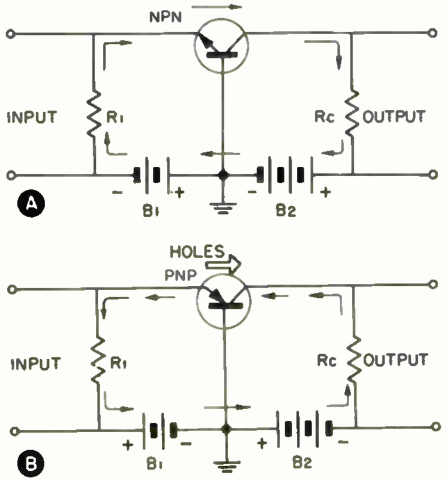


Fig. 1. Basic common-base circuits. The circuit at (A) is for an NPN transistor; the one at (B) for a PNP transistor.

In Fig. 1B the positive terminal of B1 is connected to the emitter through resistor R1. The positive potential applied to the emitter will attract electrons from the emitter. When an electron is attracted from the emitter it will flow in the direction indicated by the solid arrows, through resistor R1 to the positive terminal of B1. Meanwhile, when an electron is pulled from the emitter, a hole is created. The hole travels through the transistor in the direction indicated by the outlined arrow. The hole crosses the emitter-base junction, then travels through the base, across the base-collector junction, and to the terminal of the collector that is connected to the collector resistor R_C. There the hole is filled by an electron and disappears. The electrons needed to fill the holes reaching the collector terminal are supplied by battery B2. Thus there will be an electron flow from the negative terminal of this battery through the resistor R_C to the collector terminal of the transistor as shown by the solid arrows on the diagram.

You will remember from the preceding lesson that the majority carriers diffusing across the junctions in a transistor set up potential barriers which prevent an additional flow of majority carriers across the junction. In the transistor circuits shown in Fig. 1, battery B1 places a forward bias on the emitter-base junction that partially overcomes this potential barrier and allows some majority carriers to cross the junction. The exact number of majority carriers that will cross the junction depends upon the characteristics of the transistor and upon the voltage of battery B1. Thus, in the circuits shown in Fig. 1, we will have a static current flowing. Static current is simply a fixed current or a current flow that depends upon the operating voltages applied and not upon the signal voltage. This current is often called the "zero-signal" current, and it will set up a voltage drop across the collector resistor R_C.

A COMMON-BASE NPN AMPLIFIER

Now let us see what happens when a signal voltage is applied to the input of these transistor circuits. In Fig. 2 we have shown a common-base amplifier circuit using an NPN transistor. Let's see how this circuit can be used to amplify a signal.

Let us consider first the voltage across R_C. The end of R_C that is connected to battery B2 is essentially at signal ground potential. This is because B2 is a low impedance at signal frequencies or is made to act like a low impedance by shunting it with a capacitor. So let's consider this end of R_C as being at ground or zero potential and see what the voltage is at the other end.

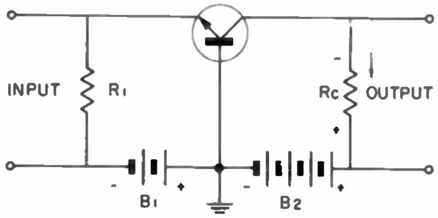


Fig. 2. A common-base amplifier circuit using an NPN transistor.

Since current flows through R_C in the direction shown, the end of R_C connected to the collector is negative. We can show this on a graph as in Fig. 3A. The voltage is negative so we represent it by a line drawn below the zero-voltage axis.

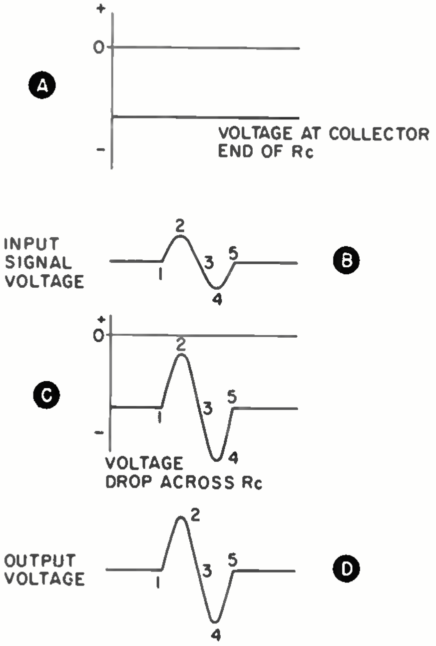


Fig. 3. Voltage waveforms for the circuit of Fig. 2.

Now, what happens when we apply a signal like Fig. 3B to the input? Consider first the input signal at point 1 in Fig. 3B. At point 1 the signal is zero and hence it has no effect on the static or zero-signal current flowing through the transistor. The only current flowing will be the zero-signal current due to the battery voltages. Therefore the voltage across R_C can be represented by the straight line extending to point 1 in Fig. 3C. Now as the ac signal moves to point 2 on the input curve, we have a voltage drop across resistor R1. The polarity of this voltage drop makes the end of R1 connected to the emitter positive and the end connected to the battery negative. This means that the polarity is opposite to the polarity of B1. Therefore the voltage across R1 will subtract from the voltage of battery B1 insofar as the net emitter-base voltage is concerned. This means that the signal will reduce the forward bias applied between the emitter and base and hence reduce the number of majority carriers (electrons) that can cross the emitter-base junction. When the number of carriers crossing this junction decreases, the number of electrons flowing through R_C will decrease.

When the number of electrons flowing through R_C decreases, the voltage drop across the resistor will decrease. This is shown in Fig. 3C. The curve rises, gets closer to zero, between points 1 and 2. This shows that the voltage is decreasing.

When the input voltage drops to point 3, we once again have the situation where the input voltage is zero. The current flowing through the collector resistor R_C will increase to the zero signal current, and the output voltage shown in Fig. 3C will increase to the zero signal voltage, point 3, which is the voltage that appeared across this resistor before any signal was applied. Hence the current will increase.

Now let us see what happens when the input signal swings in the opposite direction. When the signal swings to point 4, the end of resistor R1 that is connected to the emitter will be negative and the end connected to the battery will be positive. Now we have a voltage across R1 that is in series with the voltage of battery B1 and hence adds to it. This means that the forward bias across the emitter-base junction will be increased and the number of majority carriers crossing the junction will increase. The current flow through R_C will increase. When current flow through this resistor increases, the voltage drop across the resistor will increase and the end of the resistor that is connected to the collector will become more negative with respect to the other end. Hence the voltage appearing across the output terminals will swing to point 4 as shown in Fig. 3C. When the input signal drops back to point 5 or zero signal voltage, the voltage across the output similarly will fall back to zero signal voltage at point 5 on the output voltage curve.

Now let's consider what is happening in the output of this amplifier. First we have a dc voltage across R_C; this is the static or zero signal voltage. When a signal is applied to the input, the zero signal voltage varies. If we remove the zero signal voltage, which we can easily do by taking the output off through a capacitor, we have the output voltage shown in Fig. 3D. This is the actual amplified output obtained from the transistor.

Two important things to notice in this circuit are that the output voltage is in phase with the input voltage and that the output voltage is several times the input voltage. In other words when the input voltage swings positive, the output voltage goes positive and when the input voltage goes negative, the output voltage goes negative. We can obtain a voltage gain using this type of circuit.

A COMMON-BASE PNP AMPLIFIER

When a PNP transistor is used as an amplifier in a common-base circuit as shown in Fig. 4, the output voltage is also in phase with the input voltage. However, the way in which this circuit operates is quite different from the way the NPN circuit operates.

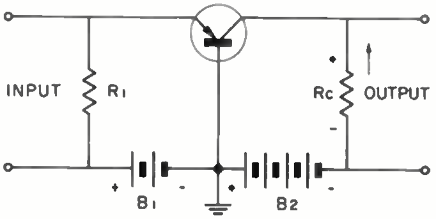


Fig. 4. A common-base amplifier circuit using a PNP transistor.

Notice that the polarity of the voltage across R_C is the opposite to what it was in Fig. 2. In Fig. 4, the end of the resistor connected to the collector is positive and the end connected to battery B2 is negative. Thus the voltage at the collector end of R_C will be positive with respect to the other end of the resistor, and under zero signal conditions can be represented by a straight line above the zero axis as shown in Fig. 5A.

Now, what happens when an input signal like Fig. 5B is applied to this circuit? When the input voltage is zero, the collector current flowing through R_C will be the zero signal current as shown in Fig. 5C extending to point 1 on the curve. But when the voltage applied across R1 swings positive to point 2 in Fig. 5B, the emitter end of this resistor is positive, and the end connected to the battery will be negative. This means that the voltage will be in series with the voltage of battery B1 and hence will increase the forward bias on the emitter-base junction. This will cause an increased movement of holes through the transistor and hence an increase in current flow through R_C. The increase in current flow through R_C results in an increased voltage drop across R_C so that the end of the resistor connected to the collector becomes more positive with respect to the other end. Thus when the input voltage moves from point 1 to point 2 in Fig. 5B, the voltage across R_C will move from point 1 to point 2 as shown in Fig. 5C.

Similarly, when the input voltage swings negative, the voltage across R1 will subtract from the forward bias applied across the emitter-base junction, reducing the bias. This will reduce the hole movement

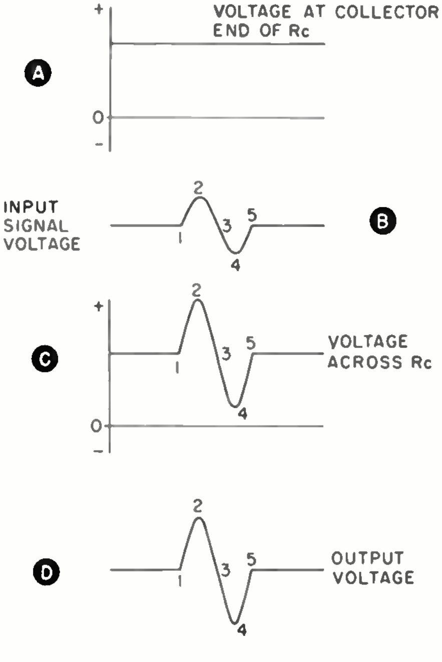


Fig. 5. Voltage waveforms for the circuit of Fig. 4.

through the transistor, which will reduce the number of electrons flowing through R_C. When the number of electrons flowing through this resistor decreases, the voltage drop across the resistor decreases with the result that the end of the resistor connected to the collector will become less positive with respect to the other end. This means that when the input signal swings from point 3 to point 4 on the input curve as shown in Fig. 5B, the signal voltage appearing across R_C will swing from point 3 to point 4 as shown in Fig. 5C.

If we once again remove the zero signal current from our graph, we have the graph shown in Fig. 5D. This represents the actual output signal voltage and, as you can readily see, it is in phase with the input signal.

CHARACTERISTICS OF COMMON-BASE CIRCUITS

Even though the action of the PNP transistor is quite different from the action of the NPN transistor, the net result using the common-base circuit is the same with both types of transistors. In both cases we have the output voltage in phase with the input voltage, and we have voltage amplification. In other words, the output signal voltage is greater than the input signal voltage.

You will remember that when you studied this circuit in the preceding lesson you learned that not all majority carriers leaving the emitter and crossing the emitter-base junction will reach the collector. Some of these carriers will be attracted by the potential of the emitter-base battery and flow out of the base to the battery. Therefore, since all of the emitter current does not reach the collector, the collector current will be less than the emitter current. Technicians say that the current gain is less than 1. For example, if the current in the emitter circuit increases by 1 milliampere, the current in the collector circuit will increase, but the increase will be something less than 1 milliampere.

Two other characteristics of a transistor amplifier that are important are the input impedance and the output impedance. The input impedance is simply the ratio of the signal voltage over the signal current. If we represent the signal voltage by e_{IN} and the signal current by i_{IN} and the impedance by Z_{IN} then the input impedance will be:

$$Z_{IN} = \frac{e_{IN}}{i_{IN}}$$

The output impedance is the ratio of the output signal voltage over the output signal current. If we represent the output signal voltage by e_{OUT} and the output current by i_{OUT} and the output impedance by Z_{OUT}, then the output impedance will be:

$$Z_{OUT} = \frac{e_{OUT}}{i_{OUT}}$$

If we examine the common-base circuit shown in Fig. 2, we see that the input voltage is applied across R1. This will cause some signal current to flow through the resistor R1. In addition, the entire emitter current drawn by the transistor must flow through R1. Therefore, even with the small signal voltage the signal current must be quite high. This means that the ratio of the voltage divided by the current will be low or, in other words, we will have a low input impedance.

On the other hand, since the stage is capable of giving voltage gain, the output voltage which will be developed across R_C will be much higher than the input voltage. At the same time, since the collector current is less than the emitter current the signal current flowing in the output will be lower than the signal current flowing in the input. Therefore the output impedance will be considerably higher than the input impedance. In fact, the output impedance will be quite high. Therefore in the common-base amplifier we have a very low input impedance and a reasonably high output impedance.

COMMON-BASE AND GROUNDED-GRID CIRCUITS COMPARED

The common-base circuit is often compared to the grounded-grid vacuum tube circuit. The two circuits are shown in Fig. 6 for comparison purposes. Notice the similarity between the common-base circuit shown at A and the grounded-grid circuit shown at B. The battery shown between the grid and the cathode of the grounded-grid circuit is seldom found in practice, because resistor R1 can be made to supply the bias required by the tube or, in some instances, a resistor placed in the grid circuit is used to develop bias. In this case the grid resistor will be bypassed by a capacitor.

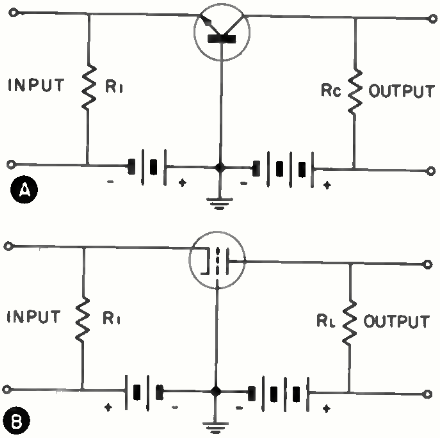


Fig. 6. Comparison of a common-base transistor circuit (A) with a grounded-grid vacuum tube circuit (B).

SUMMARY

The common-base circuit has a very low input impedance and a high output impedance. This output voltage is in phase with the input voltage and is greater than the input voltage. The current gain of the stage is less than one. A common-base circuit is often used in applications where we want to match a low impedance to a high impedance.

SELF-TEST QUESTIONS

(a) In the common-base circuit, is it possible to get a current gain?

(b) What is the phase relationship between the amplified signal voltage and the input signal voltage in a common-base circuit?

(c) What are the majority carriers in a common-base circuit using a PNP transistor?

(d) Why is it possible to get a voltage gain in a common-base amplifier circuit even though we do not have a current gain?

(e) What are the relative input and output impedances of the common-base amplifier circuit?

(f) To what type of vacuum tube circuit can the common-base circuit be compared?

The Common-Emitter Circuit

The most frequently used transistor circuits are the common-emitter circuits shown in Fig. 7. The circuit shown at A is for an NPN transistor, and the circuit shown at B is for a PNP transistor. Battery B1 in both cases provides the forward bias needed for the emitter-base junction, and battery B2 provides the reverse bias needed for the base-collector junction. In Fig. 1A battery B1 was connected so that the emitter was made negative with respect to the base. In Fig. 7A the emitter is also made negative with respect to the base. This provides forward bias for the emitter-base junction of the NPN transistor.

The solid arrows on the two diagrams in Fig. 7 indicate the direction of electron flow in the circuit. In Fig. 7A electrons leave the negative terminal of B1 and flow to the emitter. They cross the emitter-base junction, then flow through the base, across the base-collector junction, and through resistor R_C to the positive terminal of B2.

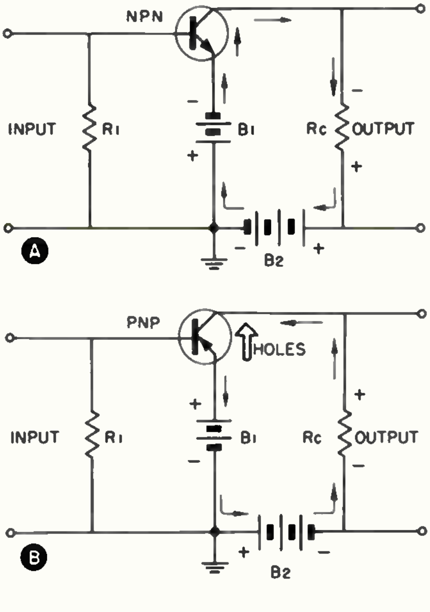


Fig. 7. Common-emitter circuits for (A) an NPN transistor, and (B) a PNP transistor.

In the circuit shown in Fig. 7B the electrons are attracted from the emitter by the positive potential of B1 and flow to the positive terminal of B1. The electrons leaving the emitter leave holes behind. These holes flow through the emitter, across the emitter-base junction, through the base, across the base-collector junction, and to the terminal of the collector. Here the holes are filled by electrons supplied by battery B2. The electrons from B2 leave the negative terminal of the battery, flow through the collector resistor R_C and to the terminal of the collector.

Notice the difference between these circuits and the common-base circuits shown in Fig. 1. In the common-base circuits, the useful transistor current flows through the input resistor R1, whereas in the circuits shown in Fig. 7, the useful transistor current does not flow through R1. The result is that the common-emitter circuit has a much higher input resistance than the common-base circuit. This is an advantage because it means that the generator driving the common-emitter circuit does not have to have such a low output impedance.

Notice that in the two circuits shown in Fig. 7 electrons flow through the collector resistor R_C in opposite directions. In the circuit shown at A, the electrons flow from the collector through the resistor to the battery, making the end of the resistor connected to the collector negative with respect to the other end. In the circuit shown at B, electrons flow from the negative terminal of B2 to the collector, making the end of the resistor connected to the battery negative with respect to the end connected to the collector. In other words, the polarity of the voltage across R_C in the circuit shown in Fig. 7A is opposite to the polarity of the voltage across R_C in the circuit shown in Fig. 7B. Now let us see how this type of circuit works.

A COMMON-EMITTER NPN AMPLIFIER

A common-emitter circuit using an NPN transistor is shown in Fig. 7A. As in the common-base circuit you just studied, battery B2 is a low impedance (or can be bypassed by a capacitor to make it act like a low impedance); therefore, the end of R_C connected to the battery is at signal ground potential. Since current flows through the resistor in the direction shown by the arrows, the end of R_C connected to the collector will be negative with respect to the end connected to the battery. The polarity of the end of the resistor connected to the collector can be represented by the straight line drawn below the zero axis as shown by curve 1 of Fig. 8A.

Now let us consider what happens when an input signal is applied to the input, as shown in curve 2 of Fig. 8A. At point 1, the input voltage is zero, and the only current flowing through the transistor is caused by the battery voltages. The signal voltage across R_C at that instant is zero and identified at point 1 on curve 3 of Fig. 8A. Now when the input signal swings in a positive direction so that the end of R1 connected to the base is positive and the end connected to ground is negative, the voltage across resistor R1 will be in series with the voltage of battery B1. This will increase the forward bias applied across the emitter-base junction of the transistor. This will increase the number of electrons crossing the emitter-base junction and hence increase the number of electrons flowing through the transistor to the collector. Therefore the number of electrons flowing through resistor R_C will increase, and the voltage drop across the resistor will increase, making the end of the resistor connected to the collector more negative with respect to

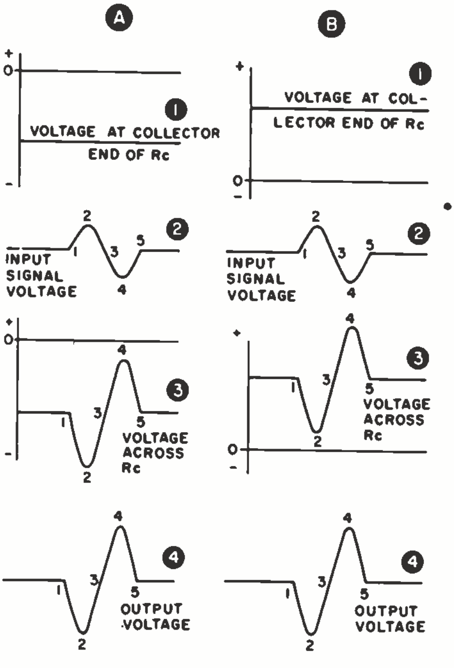


Fig. 8. Voltage waveforms for the circuits of Fig. 7. (A) is for the NPN transistor circuit, and (B) is for the PNP transistor circuit.

the end connected to the battery. Thus the output voltage will swing in a negative direction to point 2 on the output voltage curve, 3 of Fig. 8A.

As the input voltage drops back to zero, the forward bias applied across the emitter-base junction will decrease until, when the signal voltage reaches point 3, the forward bias will be made up of only the battery voltage and zero-signal current will be flowing through R_C. The voltage across R_C will drop to point 3 on the output voltage curve, 3 of Fig. 8A.

When the polarity of the input signal reverses, making the end of R1 that is connected to the base negative and the end connected to ground positive, the input voltage across resistor R1 will oppose the bias voltage applied between the emitter and base by battery B1. Thus the forward bias applied across the emitter-base junction will decrease, and the current flowing across this junction will decrease. When the current flowing across this junction decreases, the collector current, and hence the current flowing through load resistor R_C, will decrease. When the current flowing through this resistor decreases, the voltage drop across it will decrease, and the voltage at the end of the resistor connected to the collector will approach zero. This is represented by point 4 on curve 3 of Fig. 8A.

Finally, when the input signal voltage again drops to zero as shown at point 5 on curve 2 of Fig. 8A, the voltage across R_C will again increase in a negative direction until it reaches point 5 on curve 3 of Fig. 8A.

In curve 4 we have shown the output signal voltage that can be obtained by removing the dc component of the total voltage appearing across the resistor R_C. Again, this dc component can easily be removed by connecting a capacitor in series with one of the output leads.

Compare the output voltage curve shown in 4 of Fig. 8A with the input voltage shown in 2 of Fig. 8A. Notice that when the input voltage swings positive to point 2, the output voltage swings negative to point 2. Similarly, when the input voltage swings in a negative direction to point 4, the output voltage swings in a positive direction to point 4. This means that when the input is going in a positive direction, the output is going in a negative direction. In other words, the output signal voltage appearing across the load resistor R_C is 180° out-of-phase with the input signal voltage appearing across R1. From this we can conclude that when an NPN transistor is used in a common-emitter circuit, the amplified output voltage will be 180° out-of-phase with the input voltage. Also notice when comparing curve 4 with curve 2 that the amplitude of curve 4 is greater than the amplitude of curve 2. In other words, there is a voltage gain in this circuit.

A COMMON-EMITTER PNP AMPLIFIER

Although we have a somewhat different situation in a common-emitter amplifier using a PNP transistor, the net result is the same.

In a common-emitter amplifier using a PNP transistor, as shown in Fig. 7B, the electron current through resistor R_C is in the opposite direction to what it was in the amplifier using the NPN transistor. In the PNP amplifier, the electrons flow from the negative terminal of battery B2, through load resistor R_C into the collector to fill the holes crossing the base-collector junction. The electrons flowing through load resistor R_C set up a voltage drop across it having a polarity such that the end of the resistor connected to the collector is positive with respect to the end connected to the battery, as shown in Fig. 7B. Thus, if we plot the voltage at the collector end of this resistor with respect to the other end we have a curve like the one shown in 1 of Fig. 8B. Here the zero-signal voltage across R_C is represented by a straight line drawn above the zero voltage axis to indicate the fact that this voltage is positive.

Now, when an input signal like the one shown in curve 2 of Fig. 8B is applied across R1, the collector current will vary as before. When the input signal swings positive so that the end of R1 that is connected to the base is positive and the end connected to ground is negative, the voltage across R1 will oppose the voltage of battery B1, thus reducing the forward bias applied across the emitter-base junction. When the forward bias is reduced, the number of holes crossing this junction and traveling through the base, across the base-collector junction to the collector terminal is reduced. If the number of holes reaching the collector is reduced, the number of electrons flowing through R_C to fill the holes reaching the collector will be reduced. Hence the voltage drop across R_C will decrease, in other words drop toward zero. This is shown by curve 3 of Fig. 8B. When the input voltage shown in curve 2 swings in the positive direction, from point 1 to point 2, the output voltage across R_C moves from point 1 to point 2 on curve 3 of Fig. 8B.

When the input signal applied across R1 swings in a negative direction so that the end of R1 that is connected to the base is negative and the end connected to ground is positive, the voltage across resistor R1 will be in series with the voltage of battery B1 and will add to the forward bias applied across the emitter-base junction by the battery. This increased forward bias will result in an increase in the number of holes crossing the emitter-base junction which will, in turn, mean that there will be an increase in the number of holes reaching the collector. If more holes reach the collector, more electrons will have to flow through the output load resistor, R_C, to fill these holes. The result will be that the voltage drop across this resistor will increase above the zero-signal voltage level, and the end of R_C connected to the collector will become more positive with respect to the end connected to B2. This increase in voltage is shown as point 4 on curve 3 in Fig. 8B.

The complete cycle across R_C obtained with an input voltage such as shown in curve 2 is shown in curve 3 of Fig. 8B. When the dc component across resistor R_C is removed, we have the results shown by curve 4 of Fig. 8B. Notice that once again the output signal is 180° out-of-phase with the input signal.

By comparing the NPN amplifier with the PNP amplifier, you can immediately see that, although the action is somewhat different in the two circuits, the net results are the same. In both cases we have voltage amplification, and in both cases we find that in the common-emitter circuit the output signal is 180° out-of-phase with the input. Another way of saying this is that a common-emitter amplifier reverses the phase of the signal.

CHARACTERISTICS OF A COMMON-EMITTER CIRCUIT

The common-emitter circuit is the most important of all transistor circuits; it is by far the most widely used.

It is quite easy to get relatively high gain using the common-emitter circuit. Voltage gains from 80 to 100 are quite easily obtained. You can also obtain a current gain with this circuit.

Although the input impedance of this circuit is not as high as the input impedance of a vacuum tube circuit, it is substantially higher than the input impedance of the common-base circuit. Therefore it can be driven by a much higher impedance device than a common-base circuit. In a typical common-emitter circuit we usually have an input impedance of somewhere between 1000 and 2000 ohms. The output impedance is not quite as high as the output impedance of the common-base circuit, but it is still high, usually having a value of around 20,000 ohms.

COMMON-EMITTER AND GROUNDED-CATHODE CIRCUITS COMPARED

Because of circuit similarities and performance similarities, the common-emitter circuit can be compared to the grounded-cathode vacuum tube circuit. The grounded-cathode is the most common of all vacuum tube circuits. With it, as with the common-emitter transistor circuit, it is possible to obtain voltage gains of 80 to 100, and the phase is shifted 180°.

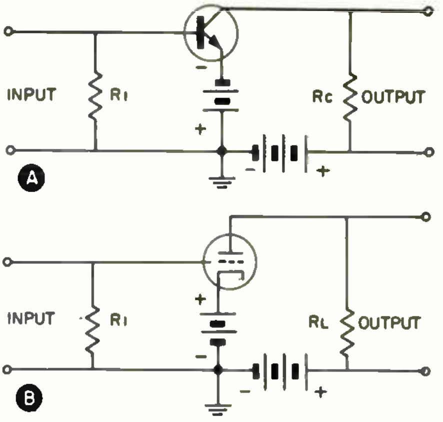


Fig. 9. Comparison of common-emitter transistor circuit (A) and grounded-cathode vacuum-tube circuit (B).

In order to help you see the similarity between these two circuits, the common-emitter circuit and the grounded-cathode vacuum tube circuit are shown in Fig. 9. The battery shown in the cathode circuit of the grounded-cathode amplifier is not found in actual practice because a resistor can be used in this circuit to avoid the necessity of this extra battery. You will see later that similar arrangements are used in transistor circuits to avoid the necessity of using two batteries to operate a single stage.

SUMMARY

The common-emitter circuit is the most frequently used transistor circuit. The voltage gain is from 80 to 100 and there is also considerable current gain. It has a medium input resistance and an output resistance of about 20,000 ohms. The output signal is 180° out-of-phase with the input signal.

SELF-TEST QUESTIONS

(g) Is it possible to get a current gain using the common-emitter circuit?

(h) What is the relationship between the input signal voltage and the amplified output signal voltage?

(i) How does the input impedance of the common-emitter circuit compare with the input impedance of the common-base circuit?

(j) Draw schematic diagrams of common-emitter circuits using NPN and PNP transistors. You should do this from memory since it is important that you remember these circuit configurations.

(k) To what vacuum tube circuit can the common-emitter circuit be compared?

The Common-Collector Circuit

The third possible circuit configuration using a triode transistor is the common-collector circuit. In this type of circuit the collector is operated at signal ground potential. Although this circuit is not found as often as the common-emitter circuit, it does have some characteristics that are useful in some special applications.

A common-collector circuit using an NPN transistor is shown in Fig. 10A, and one using a PNP transistor is shown in Fig. 10B. The arrows on the diagram in Fig. 10A show the direction of electron flow through the circuit. The solid arrows in 10B show the electron flow, and the outlined arrow indicates the direction of hole movement through the PNP transistor. Compare the circuits shown in Fig. 10 with the common-base circuits shown in Fig. 1 and the common-emitter circuits shown in Fig. 7. Let's see how each of these circuits works.

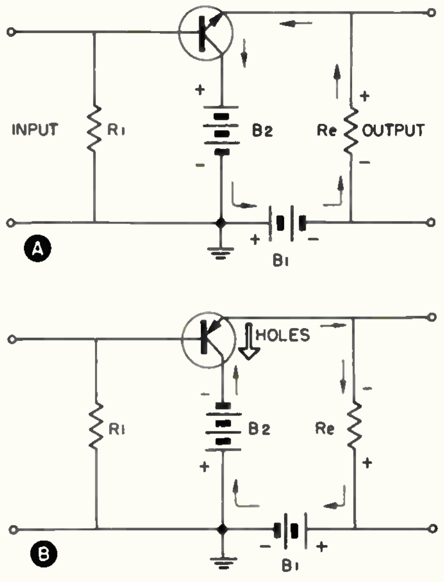


Fig. 10. Common-collector circuits. (A) for an NPN transistor, and (B) for a PNP transistor.

A COMMON-COLLECTOR NPN AMPLIFIER

In the circuit shown in Fig. 10A, electrons flow from the negative terminal of B1 through the emitter resistor Re to the emitter. They flow across the emitter-base junction, through the base, across the base-collector junction, to the positive terminal of B2. Battery B1 biases the emitter-base junction in a forward direction, whereas B2 biases the base-collector junction in a reverse direction.

Electrons flowing through Re set up a voltage drop across Re with the polarity indicated on the diagram. The end of the resistor connected to the emitter is positive with respect to the end connected to the battery. If we plot the voltage at the emitter end of the resistor, it will be like curve 1 of Fig. 11A. The voltage is represented by a straight line drawn above the zero voltage axis to indicate that it is positive with respect to the other end of the resistor.

Now let us consider what happens when an input signal like that shown by curve 2 of Fig. 11A is applied across the input terminals. When this signal swings in a positive direction from point 1 to point 2, the end of R1 connected to the base will be positive and the other end will be negative.

This means that the voltage across R1 will be in series with battery B1 and will add to the forward bias ap-

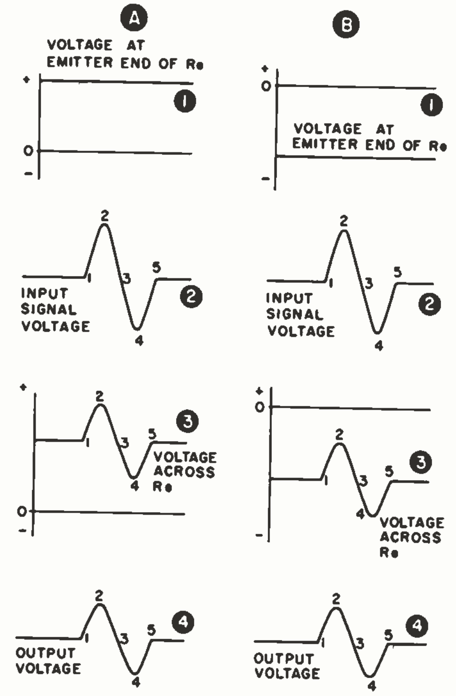


Fig. 11. Voltage waveforms for the circuits of Fig. 10. (A) is for the NPN transistor circuit; (B) is for the PNP transistor circuit.

plied across the emitter-base junction. This will increase the flow of electrons across this junction, and hence increase the current flow through the circuit and through Re. The increase in current through Re will result in an increase in the voltage drop across Re. This means that the end of the resistor connected to the emitter will become more positive with respect to the other end. The change in the voltage is indicated by points 1 and 2 on curve 3 of Fig. 11A.

Let's stop for a minute and consider what happens to the voltage applied across the emitter-base junction at this time. When the volttage across Re increases, it subtracts from the total voltage across the emitter-base junction. You will notice that the voltage across Re opposes the voltage of battery B1. Therefore an increase in the voltage across Re results in an increase in the opposition to the voltage of battery B1. When the input signal swings in a positive direction, the voltage across Re increases, opposing the increase in emitter-base voltage producing it. In other words, we have 100% voltage feedback. All of the amplified voltage appearing across Re opposes the input voltage producing it.

When the voltage across R1 swings in a negative direction as shown between points 3 and 4 on the input voltage curve, 2 of Fig. 11A, the input voltage will oppose the voltage of battery B1. This will reduce the emitter-base bias, resulting in fewer electrons crossing the emitter-base junction. This means that the current flowing in the circuit will decrease, and therefore the voltage across Re will decrease. This is shown between points 3 and 4 on curve 3 of Fig. 11A. This decrease in the voltage across Re will result in a reduction of the opposition of this voltage to the voltage of battery B1. In other words, we again have a situation where the output signal voltage being produced across Re is opposing the input signal voltage producing it.

In curve 4 of Fig. 11A we have shown the output voltage with the dc component removed. Notice that this voltage is in phase with the input voltage. Also notice that this voltage is smaller than the input voltage. Since we have 100% voltage feedback in this circuit, the output voltage will always be less than the input voltage. This situation is similar to the situation in the grounded-plate or cathode-follower vacuum tube amplifier. This transistor circuit is often compared to the grounded-plate amplifier, and we will soon see the similarity between these two circuits.

A COMMON-COLLECTOR PNP AMPLIFIER

In the common-collector circuit using a PNP transistor, the polarity of the voltage across Re is the opposite of what it was with the NPN transistor. Thus the voltage at the emitter end of resistor Re is represented by a straight line drawn below the zero signal axis as shown by curve 1 of Fig. 11B. In curve 2 of Fig. 11B we have shown an input signal similar to the one shown in curve 2 of Fig. 11A. When this input signal swings in a positive direction so that the end of R1 connected to the base is positive and the grounded end is negative, the voltage across R1 will oppose the voltage of battery B1. This will reduce the forward bias applied across the emitter-base junction and reduce the number of holes crossing this junction. You will remember that holes are formed in the emitter by pulling the electrons off the emitter. If fewer holes are formed, fewer electrons will be pulled off the emitter, and hence the current flowing through Re will decrease. When the current flowing through Re decreases, the voltage drop across Re decreases. This can be seen between points 1 and 2 on curve 3 of Fig. 11B.

When the input voltage applied across R1 swings in a negative direction as between points 3 and 4 of curve 2, the end of resistor R1 connected to the base will be negative and the grounded end positive. The voltage across R1 will be in series with battery B1 and will add to the emitter-base forward bias. This will result in an increase in the number of holes crossing the emitter-base junction. More electrons will therefore be pulled out of the emitter to produce additional holes across this junction. The current flowing through Re will increase, resulting in an increase in the voltage drop across Re. This increase is shown between points 3 and 4 on curve 3 of Fig. 11B.

Once again we have shown the output signal voltage in curve 4. Notice this is identical to the output signal voltage obtained with the NPN transistor. Notice that although the basic operation of the two circuits is somewhat different, the net result is the same. In both cases we have 100% voltage feedback, so the output is less than the input. Also notice that in both cases the output signal voltage is in phase with the input signal voltage.

CHARACTERISTICS OF COMMON-COLLECTOR CIRCUITS

The common-collector circuit has several interesting characteristics. It has the highest input impedance of the three circuits. You can see why this is true if you refer to Fig. 10. The input impedance will be the ratio of the input voltage over the input current. The voltage applied across resistor R1 will cause a certain current to flow through it. In addition, this input voltage will cause a signal current to flow from the emitter, through the transistor, to the collector. In the circuit shown in Fig. 10A, part of the electrons travelling from the emitter to the collector will be attracted by the base and hence will flow through R1. However, since the output signal voltage subtracts from the input signal voltage insofar as signal voltage applied between base and emitter is concerned, the actual signal current flowing through the transistor will be quite small. Therefore the total input signal current will be small and this, in turn, will result in the input impedance being high. On the other hand, the output impedance of the transistor will be low. This is due to the fact that the emitter signal current flows through the resistor Re and that very little voltage will be developed across this resistor. As a matter of fact, the voltage cannot be equal to the input signal voltage because if it was it would cancel the signal voltage entirely. Therefore, since the output voltage is small, the ratio of the voltage divided by the current will be small and the output impedance will be low.

In a common-collector circuit the voltage gain is always less than one. This means that the output voltage will always be less than the input voltage. We have already pointed out that this must be true because otherwise the output voltage would completely cancel the input voltage. Of course, this is impossible because it is the input voltage that causes the current change through the transistor which in turn develops the output voltage. All of the output voltage is fed back into the input circuit and therefore we say that we have 100% voltage feedback.

The common-collector circuit has the best stability of the three transistor circuits. This is what you might expect because, with the low output voltage, there is very little voltage to produce feedback into the input circuit which could cause instability or oscillation. Also, there is no phase reversal in the circuit and therefore the output voltage is in phase with the input voltage.

We have redrawn the common-collector circuit in Fig. 12A to make it easier to compare it with a cathode-follower or grounded-plate vacuum tube circuit shown in Fig. 12B. Notice the similarity between the cathode - follower and common collector circuit.

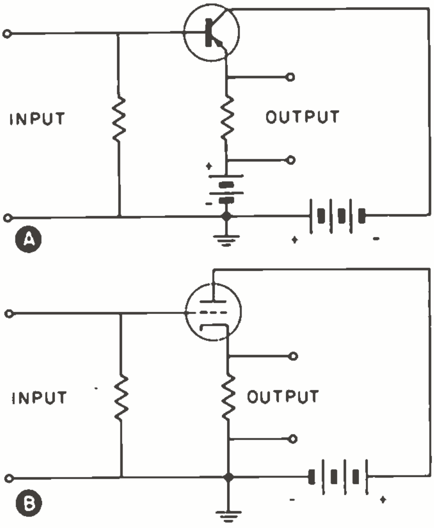


Fig. 12. Comparison of a common-collector transistor circuit (A) and a cathode-follower vacuum-tube circuit (B).

Because the common-collector circuit has a high input impedance and a low output impedance it is often used as an impedance matching device to match a relatively high impedance to a low impedance. An excellent use of this type of circuit is in the video amplifier of color TV receivers. In a color TV receiver a delay line, that slows up or delays the video signal, is used in the video amplifier. This delay line is used so that the brightness signals being fed to the color picture tube will be slowed down a little so that they will arrive at the picture tube at the same time as the color signal. A delay line is a comparatively low impedance device and the common-collector circuit provides an excellent method of matching from the higher impedance video amplifier stages to the low impedance of the delaying line. It is quite likely that when more transistorized color TV receivers are manufactured, this circuit will be very useful in this application.

SUMMARY

It is important for you to understand the three basic transistor circuits. You will find that transistors in commercial equipment will be arranged in one of these three basic circuits.

The most commonly used of the three circuits is the common-emitter circuit. In this circuit, the emitter is common to both the input and the output circuits. It is operated at signal ground potential. In the common-emitter circuit a voltage gain of from 80 to 100 can easily be obtained. In addition, there will be considerable current gain in this circuit. Other important characteristics of this circuit are a medium input resistance, usually somewhere between 1000 and 2000 ohms, and an output resistance in the neighborhood of 20,000 ohms. You should also remember that this is the voltage amplifier circuit that produces a 180° phase shift. In other words, the output signal voltage will be 180° out-of-phase with the input signal voltage.

The common-base circuit is the circuit in which the base is common to both the input and output circuits. It has a very low input resistance but has the highest output resistance of the three basic circuits. The current gain is always less than 1, but this type of circuit is quite stable. In fact, temperature changes have little effect on the operation of the circuit, whereas this is not always true of the common-emitter circuit. There is no phase reversal in a voltage amplifier used in this type of circuit; in other words, the output voltage will be in phase with the input voltage.

The common-collector amplifier is an amplifier in which the collector circuit is common to both the input and output circuits. This circuit has the highest input resistance, but the output resistance is very low; it may be as low as 100 ohms. This is the only one of the three circuits that has a lower output resistance than input resistance. In this circuit the voltage gain is always less than 1 because there is 100% voltage feedback. The stability of this circuit is excellent--the best of the three circuits. Again, there is no phase reversal when this circuit is used; the output voltage is in phase with the input voltage.

SELF-TEST QUESTIONS

(l) What is the phase relationship between the output voltage and the input voltage in a common-collector circuit?

(m) What will the voltage gain of the common-collector circuit be?

(n) What are the relative input and output impedances of the common-collector circuit?

(o) To what vacuum tube circuit can we compare the common-collector circuit?

(p) In which transistor circuits will you find an output voltage that is in phase with the input voltage?

(q) Which transistor circuits give you an output signal voltage that is 180° out-of-phase with the input signal voltage?

(r) Which transistor circuits will give you a voltage gain?

(s) Which transistor circuits will give you a current gain?

(t) Which transistor circuits have a relatively high input impedance?

(u) Which transistor circuit has a low output impedance?

Transistor Characteristics

You will remember from your study of tubes that they have certain important characteristics that tell the technician a great deal about how the tube should perform. The important tube characteristics are the mutual conductance, amplification factor and plate resistance. Likewise, there are certain transistor characteristics that are important to the technician. They enable him to compare one transistor with another and to get an idea of what to expect from a transistor in a certain circuit. All of this information is helpful in determining whether or not a transistor is performing the way it should.

In addition, there are a large number of symbols used in describing transistor performance. Many of these symbols are of interest only to circuit designers and engineers, but the technician should be familiar with the more important ones and be able to evaluate from a transistor manual the important transistor characteristics. In this section of this lesson we are going to cover some of the more important symbols and transistor characteristics.

TRANSISTOR SYMBOLS

As you might expect, the letter I is used to represent current in transistor circuits. When the capital letter I is used, it indicates dc current or rms current. When the small letter i is used, it indicates instantaneous current.

Currents flowing in the various transistor electrodes are identified by means of a letter representing the electrodes. For example, the emitter current is represented by the letter E or e. Base current is represented by B or b and collector current is represented by the letter C or c. Using these symbols, the dc emitter current is designated by the symbol I_E. The rms emitter current is represented by the symbol I_e, and the instantaneous emitter current is represented by the symbol i_e. Similarly, dc base current is represented by I_B, rms base current is represented by I_b, and instantaneous base current is represented by i_b. Collector dc current is represented by I_C, rms collector current is represented by I_c, and instantaneous collector current is represented by i_c.

Two characteristics that are often referred to in transistors are the forward current and the reverse current. The symbol used to represent the dc forward current is I_F, and i_F is used to represent the instantaneous-forward current. The dc reverse current is represented by I_R and the instantaneous-reverse current is represented by i_R.

You will remember that in normal operation a transistor is operated with a forward bias across the emitter-base junction and a reverse bias across the base-collector junction. Thus in an NPN transistor, current can flow from the emitter, across the emitter-base junction, through the base, across the base-collector junction and through the collector to the positive terminal of the battery, placing the reverse bias across the base-collector junction. However, we also point out that there would be at all times some minority carriers crossing the various junctions in a reverse direction. Thus there will be a current flow across the base-collector junction due to holes travelling from the collector across the junction into the base. This reverse current is kept as small as possible because it contributes nothing to the usefulness of the transistor. As a matter of fact, the current crossing the junction tends to heat the junction and cause a number of undesirable effects. Transistor manuals often list the reverse current across the collector-base junction. The current that is listed is the current that will flow across the junction when the junction is reverse biased and the emitter is open circuited. This dc current is represented by the symbol - I_{CBO}. The letters CB indicate that the current is across the collector-base junction in the reverse direction. The letter O indicates that the other electrode, the emitter, is open. This symbol is so widely used, that it is often abbreviated I_{CO}.

Groups of symbols are used in this manner to indicate other transistor current. For example, the symbol I_{CEO} is used to represent the dc collector current with the collector junction reverse biased and the base open circuited.

There are other symbols used in conjunction with transistors, but the ones covered in this section are the most important ones for the technician to remember, along with the few new ones we will cover in the next section. If you read through this section carefully and understand how these symbols are put together, the chances are that you will be able to figure out any that you are likely to encounter that will be of importance to you.

CURRENT GAIN

As we mentioned, a transistor is primarily a current operated device. Its ability to amplify is due to the fact that it can transfer a current from a comparatively low resistant circuit to a higher-resistant circuit. One of the important characteristics of a transistor is its current gain.

Since the current gain that can be obtained with a transistor depends upon the circuit in which the transistor is used, two symbols are used for current gain. These symbols are the Greek letters alpha (α) which represents the current gain in a common-base circuit, and the Greek letter Beta (β), which is used to represent the current gain in a common-emitter circuit. The two are interrelated; let's see how and exactly what each symbol means.

Alpha.

Alpha is equal to the change in collector current divided by the change in emitter current needed to produce this change in collector current. This is often represented by the symbols:

$$\alpha = \frac{\Delta Ic}{\Delta Ie}$$

The small triangles are Greek letter deltas, which are used to indicate a change; in this case, a change in current.

You will remember that in a common-base circuit the current gain is less than 1 because the change in collector current is slightly less than the change in emitter current. This is due to the fact that not all of the carriers crossing the emitter-base junction reach the collector. Some of them are attracted to the battery in the emitter-base circuit, and some of them are lost through recombination in the base. Thus the number of carriers reaching the collector will be slightly less than the number of carriers crossing the emitter-base junction. However, in a good transistor the majority of the carriers do reach the collector so that the current gain in the common-base circuit is close to 1. Typical values run around .95, which indicates that 95% of the carriers crossing the emitter-base junction reach the collector.

Transistor manufacturers often list the alpha of a transistor in the transistor characteristics. This will immediately tell you what current gain can be obtained from the transistor used in a common-base circuit. Also, as you will see later, you can determine from this figure the current gain that will be obtained in the same transistor in a common-emitter circuit. Another characteristic often given is the alpha cut-off frequency. This is the frequency at which the current gain of the transistor in the common-base circuit drops to 70.7% of what it is at lower frequencies.

Beta.

You will remember that in the common-emitter circuit we had a current gain. This means that the value of beta will always be greater than 1.

Beta is defined as the change in collector current divided by the change in base current. It is often represented by the expression:

$$\beta = \frac{\Delta\ Ic}{\Delta\ Ib}$$

Again, the small triangles are used to indicate a change in current. Typical values of beta may run as high as 80 or 100.

Beta is another characteristic frequently found in transistor specifications. If you know the beta of a transistor, you immediately know the current gain that the transistor will give when it is used in a common-emitter circuit. From this, as you will soon see, you can also determine the current gain that will be obtained in the common-base circuit, if the value is not given in the characteristics. The beta cut-off frequency is the frequency at which the current gain of the transistor in a common-emitter circuit drops to 70.7% of what it is at lower frequencies.

Converting Values.

Manufacturers often give either the alpha or the beta of a transistor, but seldom both. Sometimes when the alpha is given you want to know the value of beta and vice versa. Actually it is quite easy to convert from one to the other. If you know the alpha of a transistor you can find beta from the formula:

$$\beta = \frac{\alpha}{1 - \alpha}$$

If you know the beta of a transistor you can find alpha from the formula:

$$\alpha = \frac{\beta}{1 + \beta}$$

Now let's work a couple of examples to see how easy it is to convert from one value to the other. Let's assume that we have a certain transistor and the manufacturer lists the value of alpha as .95. Let's find the value of beta.

Starting with the formula:

$$\beta = \frac{\alpha}{1 - \alpha}$$

We substitute .95 for alpha and get:

$$\beta = \frac{.95}{1 - .95} = \frac{.95}{.05}$$

We can eliminate the decimals in this division by moving both the decimal points two places to the right so we have:

$$\beta = \frac{95}{05} = \frac{95}{5} = 19$$

Thus if alpha is equal to .95, beta will be equal to 19.

Now let's assume we have been given the value of beta as 19 and see what value of alpha we get. We know it should be .95. Starting with the formula:

$$\alpha = \frac{\beta}{1 + \beta}$$

we substitute 19 for beta and get:

$$\alpha = \frac{19}{1 + 19} = \frac{19}{20}$$

to get the value of alpha we need only divide 19 by 20:

```
     .95
20/19.0
   18 0
    1 00
    1 00
```

so we get a value of .95 for alpha if we start with 19 for beta.

Sometimes the gain of a transistor is referred to as a forward current-transfer ratio. In other words, instead of referring to the gain in a common-base circuit we say that the forward current-transfer ratio is alpha; we know this will always be less than one. Similarly, in the common-emitter circuit we refer to beta as the forward current-transfer ratio which, in effect, is the same thing as the current gain of the transistor.

Another characteristic or term that is frequently used in transistor manuals is the gain-bandwidth product. The gain-bandwidth product is the frequency at which beta equals one. In other words, as the frequency at which the transistor is used is increased, the current gain in the common-emitter circuit will drop off. At some frequency beta will be equal to one and this is called the gain-bandwidth product.

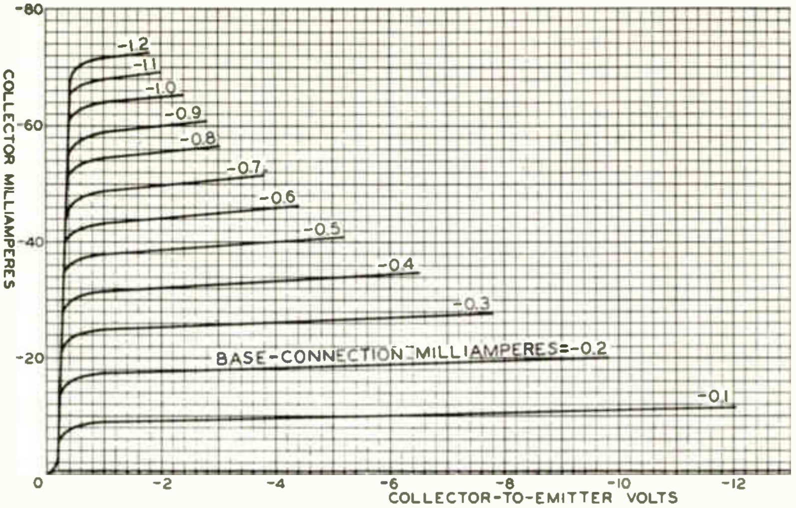
CHARACTERISTIC CURVES

When you studied vacuum tubes, you learned that characteristics are used to supply information about the manner in which a given tube performs. By means of curves a great deal of information about the tube can be condensed and presented in a convenient form. It is possible to see what the tube will do with different operating voltages and under different operating conditions.

Transistor characteristic curves are used for exactly the same reason. The curves give information about the way in which a transistor will perform in a convenient compact form.

A typical set of characteristic transistor curves is shown in Fig. 13. These curves are for a transistor used in a common-emitter circuit. They indicate what the collector current will be with different values of collector-to-emitter voltages and with different base currents. This type of curve is the most widely used transistor characteristic curve.

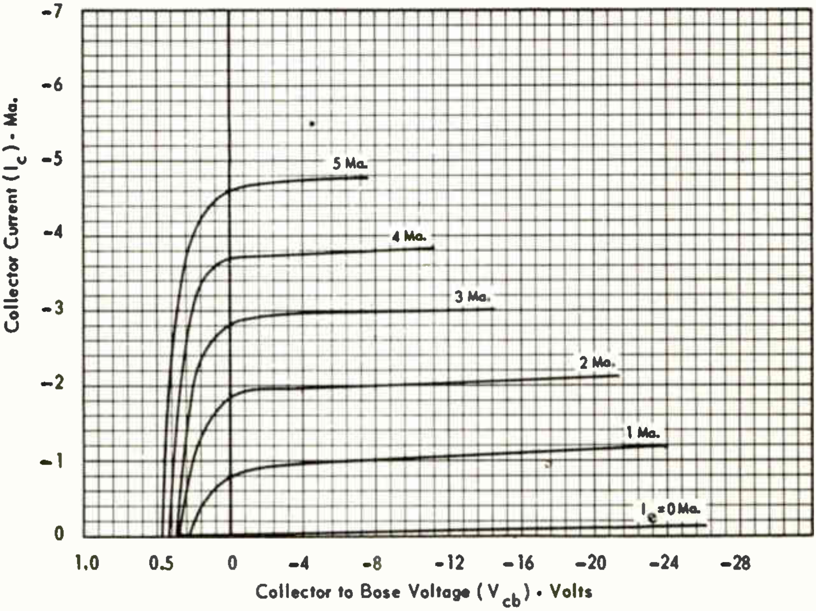
The curves shown in Fig. 13 can be used to determine the beta of a transistor for different collector-to-emitter voltages. For example, at a voltage of -4 volts, notice that when



Courtesy RCA

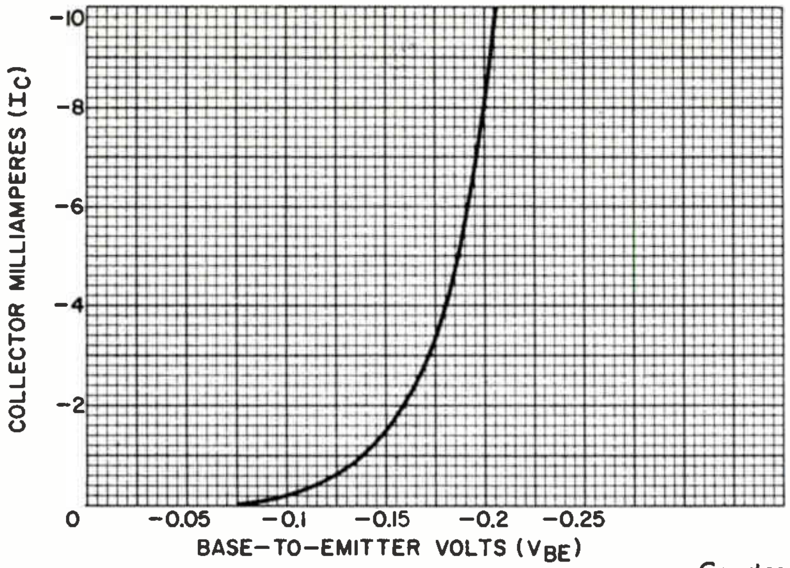
Fig. 13. Typical collector characteristic curves for a transistor used in a common-emitter circuit for different base currents.

the base current changes from -.3 milliamperes to -.4 milliamperes the collector current changes from approximately -26 milliamperes to -33 milliamperes. Thus for the change in base current of -.1 ma we have a change in collector current of -7 ma. Therefore:



Courtesy Raytheon Mfg. Co.

Fig. 14. Typical characteristic curves for a PNP transistor used in a common-base circuit for different emitter currents.



Courtesy RCA

Fig. 15. A typical transfer curve.

$$\beta = \frac{-7}{-.1} = \frac{70}{1} = 70$$

Another set of transistor characteristic curves for a PNP transistor is shown in Fig. 14. This set of curves is for a transistor used in a common-base circuit. Curves of this type are not given as often as those shown in Fig. 13 for the common-emitter circuit, since the common-emitter circuit is more widely used than the common-base circuit.

However, manufacturers often release detailed specification sheets on certain transistor types where curves of this type are given.

Another characteristic curve that is frequently given is the transfer characteristic curve, shown in Fig. 15, which enables you to find the collector current for different base-to-emitter voltages at a fixed collector-to-emitter voltage. An indication of the collector current change that might be expected with a given input voltage can be obtained from a curve of this type. The curve also indicates the range over which the transistor is comparatively linear. For example, with the base-to-emitter voltage of 100 millivolts, you can see that the collector current changes will not be linear with changes in input voltage. However, with a fixed base-to-emitter voltage of about -175 millivolts, small changes in this voltage will result in linear current changes.

SUMMARY

In this section of the lesson we have touched briefly on some of the important transistor characteristics. You learned that alpha is a term used to represent the current gain of a transistor in a common-base circuit. The alpha of a transistor is always less than 1, which means that the current gain of a transistor in a common-base circuit is always less than one.

Beta is the symbol used to represent the current gain of a transistor in a common-emitter circuit. The common-emitter circuit always has a current gain, and therefore the value of beta will always be greater than 1. Remember also that the value of beta is not constant; it depends to some extent upon the collector current.

You studied a number of important symbols that are used in transistor manuals to describe transistor performance and in many technical bulletins on transistor circuitry.

The characteristic curves studied in this lesson are typical of characteristic curves issued by transistor manufacturers. They give you an indication of what the collector current will be for different values of collector voltage and different values of emitter or base currents depending upon whether the transistor is used in a common-base or a common-emitter circuit.

Transistors are newcomers to the electronics field compared to vacuum tubes. As a result, from time to time you may see different types of characteristic curves on transistors issued by manufacturers. However, by studying the curves and the information given by the manufacturer on the transistor you can usually learn a great deal about the transistor and the type of performance you would expect from it, and from this information you can evaluate its performance in the circuit to determine whether or not it is operating properly. Being able to do this is a great help to a technician because he is able to determine whether or not he is getting all he should be able to get out of a particular circuit.

SELF-TEST QUESTIONS

(v) What are the symbols used to represent the dc currents in the various transistor electrodes?

(w) What is meant by the symbol I_{CBO}?

(x) Based on the transistor symbols you studied in this section of this lesson, what would you expect the symbol V_{CE} to mean?

(y) What is the Greek letter α used to represent in transistor circuitry?

(z) What is the maximum value that α can have?

(aa) What is meant by the forward current-transfer ratio in a common-base circuit?

(ab) What symbol is used to represent the current gain of a transistor in the common-emitter circuit?

(ac) What is meant by the alpha cutoff frequency?

(ad) What is the gain bandwidth product of a transistor?

(ae) If the beta of a transistor is 24, what is the value of alpha?

(af) Find the beta value of a transistor if alpha is equal to .99.

Typical Transistor Circuits

So far the circuits we have discussed have been basic transistor circuits. The circuits could be used in essentially these forms, but it is more convenient to modify these circuits slightly in actual usage.

The disadvantage of the circuits we have shown is that they use two separate batteries, one to supply the forward bias required across the emitter-base junction and a second battery to supply the reverse bias required across the base-collector junction. In actual practice, these circuits are modified so that both voltages can be obtained from a single voltage source. In battery-operated equipment this eliminates the need for a second battery. In equipment that operates from a power line, it simplifies the power supply somewhat so that the power supply can be arranged to provide either a positive or a negative voltage with respect to ground instead of having to supply both positive and negative voltages.

In this section of this lesson we will look at a number of typical transistor amplifier stages.

AUDIO AMPLIFIERS

A typical common-emitter audio amplifier circuit using an NPN transistor is shown in Fig. 16. Notice that the circuit is somewhat different from the common-emitter circuits you have seen previously inasmuch as only one battery is used in this circuit. Notice that the negative terminal of the battery is connected to the emitter. The positive terminal of the battery is connected to the base through the resistor R1. This would tend to make the base positive with respect to the emitter, which is what we want in order to place a forward bias across the emitter-base junction. You will remember that some of the electrons travelling from the emitter across the junction into the base leave the transistor through the base connection. These electrons will flow through the resistor R1 and set up a voltage drop across the resistor having the polarity shown. Although the number of electrons flowing through R1 will be very small, by using a large value resistor for R1 we can develop considerable voltage drop across it. Therefore even though the base is connected directly to the positive terminal of the battery through R1, the voltage drop across R1 subtracts from the battery voltage so that the net emitter-base voltage is quite small. Usually the base will be positive with respect to the emitter by only a few tenths of a volt, which is all that is required to forward bias the junction.

The collector is connected to the positive terminal of the battery through R2. The value of R2 is chosen

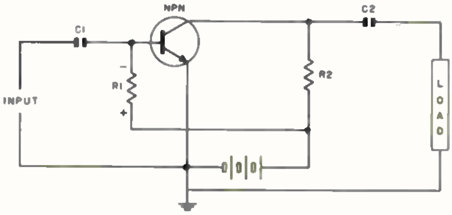


Fig. 16. A common-emitter audio amplifier using an NPN transistor.

so that the current flowing through it will result in a voltage drop across the resistor that is less than the voltage drop across R1. This means that the collector is positive with respect to the base, which is again the condition required to place a reverse bias across the base-collector junction.

In operation, the input signal causes the base-emitter forward bias to vary. This in turn causes the number of electrons crossing the emitter-base junction to vary and hence the collector current varies. The varying collector current flowing through the resistor R2 will result in an amplified signal voltage being developed across R2. This amplified signal voltage is fed to the load through the coupling capacitor C2.

In a typical circuit you will often find that both C1 and C2 are electrolytic capacitors. Electrolytic capacitors are used because the impedances found in transistor circuits are much lower than those found in vacuum tube circuits. You will remember that the capacitor C1 will act as a voltage divider along with R1 and divide the input signal in such a way that part of it will appear across the capacitor and part of it will appear across the transistor input impedance. The amount that will be lost across the capacitor will depend upon its reactance in comparison with the input impedance of the transistor. Therefore, to keep the reactance of the capacitor low, a large value capacitor is usually used.

Fig. 17 is a schematic of a common-emitter amplifier using a PNP transistor. Notice that the circuit is identical except that the battery is reversed. In this circuit, the negative terminal of the battery is connected to the base of the transistor through R1. This places a negative voltage on the base with respect to the emitter, which will forward bias the emitter-base junction. As in the previous case, however, the entire voltage will not be applied across the emitter-base junction because of the voltage drop across R1. Some electrons will flow from the negative terminal of the battery through R1 and into the base of the transistor to fill holes. This will result in a voltage drop across R1 having the polarity shown in the diagram. This voltage drop will subtract from the battery voltage so that once again the forward emitter-base bias is only a few tenths of a volt.

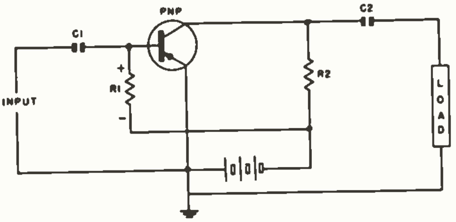


Fig. 17. A common-emitter audio amplifier using a PNP transistor.

In this circuit, as in the previous circuit, the voltage drop across R2 will be less than the voltage drop across R1, and therefore the collector will be negative with respect to the base so that we will have a reverse bias across the base-collector junction.

The operation of this circuit is essentially the same as the operation of the circuit shown in Fig. 16. The only exception is that in the transistor holes will be the majority carriers whereas in the preceding NPN transistor, electrons were the majority carriers.

Bias Stabilization.

In the circuit shown in Fig. 16 we have used an NPN transistor. In the collector region, in addition to free electrons which are the majority carriers, there will be some free holes. These holes, which are the minority carriers, will tend to cross the collector-base junction and flow into the base of the transistor. Some of the electrons travelling from the emitter across the emitter-base junction into the base will fill these holes. This is one of the reasons why the collector current will always be less than the emitter current. Some of the holes, however, will be filled by electrons that would normally leave the transistor at the base and flow through R1.

If the temperature of the transistor increases, the resistance of the base-collector junction will decrease, and this will allow additional holes to cross from the collector into the base. This, in turn, will reduce the number of electrons flowing through R1 which will reduce the voltage drop across it.

If the voltage drop across R1 is reduced, the effective emitter-base forward bias will be increased because this bias is equal to the battery voltage less the voltage drop across R1. The increase in forward bias across the emitter-base junction will result in a higher emitter current. This, in turn, will result in a higher current across the emitter-base junction, through the base, and across the base-collector junction. The increase in current across the base-collector junction will result in a further increase in the temperature of this junction which in turn will reduce the resistance again, causing the number of minority carriers crossing the junction to increase still further. This action will continue until eventually the current through the transistor becomes so high that the transistor is destroyed.

The simplest way to overcome this problem is to add a bias-stabilizing resistor in series with the emitter lead. A typical circuit in which this has been added is shown in Fig. 18. The bias-stabilizing resistor is marked R3 on the diagram. Capacitor C3 bypasses the signal around this resistor to prevent degeneration.

If a transistor heats and the base-collector junction resistance is lowered in this circuit, we will have the same situation as before; the resistance will go down and the minority carriers crossing from the collector into the base will increase. This will cause the current through R1 to go down which in turn will reduce the voltage drop across the resistor and tend to increase the emitter-base forward bias. However, the increase in forward bias will tend to cause the emitter current to increase. This increase in current will result in an increase in the voltage drop across R3. Since this voltage subtracts from the forward bias, it will tend to keep the forward bias across the emitter-base junction reasonably stable. Although there will be some increase in current, it is usually not large enough to damage the transistor.

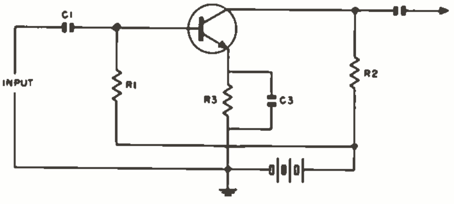


Fig. 18. A common-emitter circuit with a bias stabilizing resistor in the emitter circuit.

Common-Base Amplifier.

The common-base circuit is sometimes found in voltage amplifier circuits. This circuit is particularly useful in TV receivers where some voltage amplification is required without a phase shift. You will remember that with a common-emitter type of amplifier circuit there is a 180° phase shift, whereas in a common-base circuit there is no phase shift.

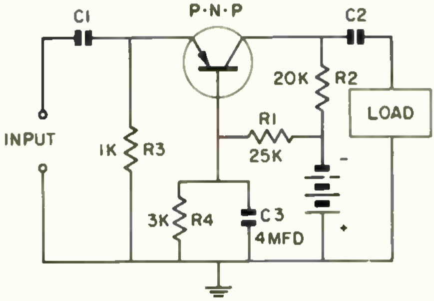


Fig. 19. A single-battery common-base amplifier with bias stabilization.

The circuit shown in Fig. 19 is a common-base circuit modified for use with a single battery. R1 and R4 make up a voltage divider which is connected across the battery. The forward bias, which is required for the emitter-base junction, is developed across R4.

The emitter resistor, R3, serves two purposes in the common-base amplifier. First, it is the impedance across which the input signal is developed. Second, it acts as a bias-stabilizing resistor. As a bias-stabilizing resistor, it works exactly like resistor R3 in Fig. 18, reducing the forward bias of the emitter-base junction if the emitter current tends to increase.

Resistors R1 and R4 are chosen such that the battery current through R1 and R4 is much greater than the base current which flows only through R1. Thus any variations in base current will have little effect on the base voltage which appears across R4. Capacitor C3 bypasses R4 and assures that the base is grounded for ac signals.

RF AMPLIFIERS

Radio frequency amplifiers are almost always tuned amplifiers. They make use of series-resonant and parallel-resonant circuits so that they can be tuned to accept one signal and reject all others. If a low resistance is connected across a parallel-resonant circuit, the resistance will load the circuit so that its selectivity will be destroyed. In other words, it will be unable to select one signal and reject another. This is one of the problems that we face with transistor rf amplifiers. Transistor amplifiers must take into account the fact that transistors are relatively low impedance devices and if they are connected directly across a resonant circuit they will load the circuit and reduce the selectivity.

A typical transistor i-f amplifier is shown in Fig. 20. Although this

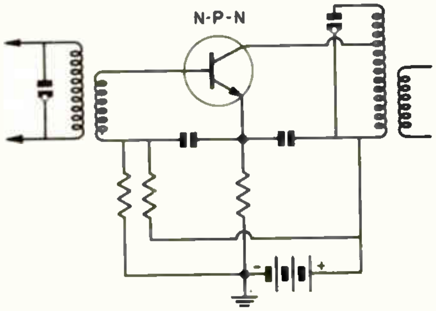


Fig. 20. Transistor input impedance matched by a step-down input i-f transformer and output impedance matched to tuned circuit by tapping down on coil.

is used as the intermediate frequency amplifier in a radio receiver, it is still a radio frequency amplifier since it is designed to amplify radio frequency signals.

Notice that instead of using a double-tuned input transformer, as used in i-f stages using tubes, a single-tuned transformer is used. The secondary of the i-f transformer has far fewer turns than the primary. Therefore the transformer acts like a step-down transformer. The low input impedance of the transistor does not load the primary of the transformer which is a parallel-resonant circuit. Insofar as the primary is concerned, the step-down transformer effectively matches it to the transistor so that excessive loading is avoided.

In the output circuit, the collector is connected to a tap on the primary winding of a second i-f transformer. The lower end of this transformer primary is connected to the positive terminal of the battery and is effectively at signal ground potential. The upper end of the transformer is at some comparatively high impedance with respect to ground. Somewhere along the transformer winding there will be a point at which the impedance of the transformer winding is equal to the output impedance of the transistor. The idea is to connect the collector to this point and by so doing match the collector to the primary winding of the transformer to get maximum signal transfer and at the same time avoid loading the parallel-resonant circuit.

As a technician, you will not have to be concerned about finding the correct impedance point at which to connect a transistor to an i-f transformer; the engineers who designed the set will have taken care of this for you. The important point for you to see is how the transistor is connected into the circuit and to understand why this provision has been made.

One disadvantage of the circuit shown in Fig. 20 is that it is somewhat unstable. This is due to the capacity and resistance across the base-collector junction. Energy can be fed from the collector circuit to the base which is connected directly to the input circuit. If the energy fed back into the input circuit is of the correct phase to reinforce or add to the input signal, the transistor may go into oscillation and generate a signal of its own.

Neutralization.

Two circuits that are used to overcome this undesirable effect are shown in Fig. 21. In both of these circuits neutralization is used to overcome the undesirable effects of feedback.

In the circuit shown in Fig. 21A, tap 2 on the primary of the output i-f transformer is operated at signal ground potential. This tap on the transformer is grounded through the .01-mfd capacitor connected from terminal 2 of the transformer to the emitter. The collector is connected to terminal 1 and signal currents flowing between terminals 1 and 2 will induce a voltage in the portion of the winding between terminals 2 and 3. Thus a voltage is set up at terminal 3 having the opposite polarity to the voltage in terminal 1. This voltage is fed through C1 back to the base of the transistor.

Now, if sufficient energy is fed from the collector of the transistor across the base-collector junction to the base to cause instability, a signal with the opposite polarity is fed through C1 to the base of the tran-

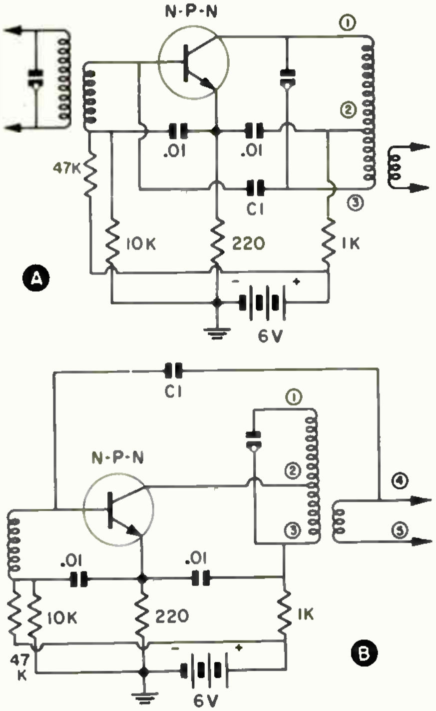


Fig. 21. Two methods of neutralizing a transistor i-f stage.

sistor. These two signal voltages tend to cancel each other so that there is not sufficient net feedback to the base to cause oscillation.

In this circuit the tuned part of the output i-f transformer consists of the entire winding between terminals 1 and 3. You will notice that this winding is tuned by a capacitor so that they form a parallel resonant circuit. Since terminal 2 is operated at ground potential and the collector is connected to terminal 1, the transistor is connected across only a portion of the i-f transformer so that it does not load the transformer excessively and reduce the selectivity of the parallel resonant circuit. At the same time, with this arrangement the instability that was encountered in the circuit shown in Fig. 20 is avoided.

The circuit shown in Fig. 21B is similar to the circuit shown in Fig. 20 except that neutralization is added by means of capacitor C1 connected from the secondary of the output i-f transformer back to the base. The polarity of the signal voltage fed through this capacitor to the base is opposite to the polarity of the signal voltage fed back through the transistor itself across the base-collector junction, so that these two signals will tend to cancel.

When a circuit like the one shown in Fig. 21B is used, the neutralizing capacitor C1 will be somewhat larger than the neutralizing capacitor C1 shown in Fig. 21A because there is quite a step-down in voltage between the primary and secondary windings of the i-f transformer. Since C1 in Fig. 21B is connected to the secondary, the voltage will be considerably lower at this point than it is at the primary. Therefore, a larger capacity is needed in order to feed sufficient voltage back to the base to prevent oscillation. The circuit shown in Fig. 21B is somewhat less critical than the circuit shown in Fig. 21A.

The gain obtained in an i-f stage using a transistor is considerably less than that obtained in an i-f stage using a vacuum tube. As a result, many receivers using transistors in the i-f amplifier have two or more i-f stages. Most modern receivers using vacuum tubes, on the other hand, have only one i-f stage.

OSCILLATOR AND MIXER STAGES

You will remember that modern radio receivers are superheterodyne receivers. In the superheterodyne receiver, the signal being received is mixed in the mixer or converter stage with a signal generated in a local oscillator. Mixing these two signals together results in the formation of two new signals, one with a frequency equal to the sum of the two frequencies and the other with a frequency equal to the difference between the two. Both signals are modulated with the original intelligence being transmitted by the broadcast station.

In modern receivers the difference signal is amplified by the i-f amplifier because the i-f amplifier is tuned to this frequency. This signal is then fed to a detector where the audio signal is separated from the carrier, and then the audio signal is amplified further and fed to a loudspeaker.

Typical mixer and oscillator circuits are shown in Fig. 22. Here an NPN transistor is used in a common-emitter mixer circuit. The primary winding of the loop antenna, L1 on the diagram, is inductively coupled to L2. The signal picked up by the loop is fed to L2 and then applied between the base and ground. This arrangement prevents the input impedance of the transistor from loading the tuned circuit. The signal from the local oscillator is fed through C1 to L2 and hence to the base of the mixer. In the mixer, the two signals beat together to produce the desired i-f signal.

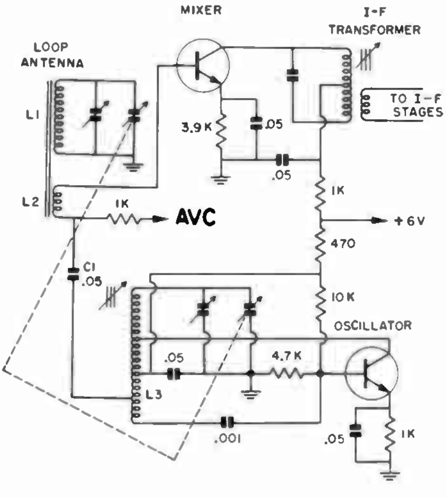


Fig. 22. Oscillator and mixer stages using separate transistors.

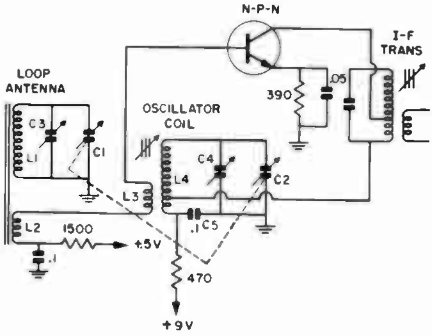


Fig. 23. A converter stage using one transistor as both oscillator and mixer.

The oscillator circuit uses another NPN transistor in a common-emitter circuit. This circuit is one form of the Hartley Oscillator which you have seen used previously with vacuum tubes.

The circuit shown in Fig. 22 works well and seldom gives trouble; it's main disadvantage is that two transistors are required. You are not likely to see this arrangement except in some of the more expensive transistor receivers. The usual practice is to use one transistor as both the mixer and the oscillator.

A converter stage, where a single transistor is used as both the mixer and oscillator, is shown in Fig. 23. Here an NPN transistor is used in a common-emitter circuit. In this circuit the signal is picked up by the loop antenna, which is inductively coupled to L2. The signal voltage is induced in series with L2, and this is applied to the base of the transistor through L3, and to ground through the .1-mfd capacitor.

At the same time, energy is fed from the collector into the primary of the i-f transformer and from the primary of the i-f transformer back to L4. L4, C2, C4, and C5 make up the oscillator tank circuit. L4 is inductively coupled to L3, and energy is fed from L3 to the base of the transistor. Thus we have two signals fed to the base of the transistor, the incoming signal picked up by the loop antenna, and the signal generated in the oscillator tank circuit. These two signals are mixed in the transistor and the resulting difference-frequency signal is selected by the i-f transformer and fed to the first i-f amplifier.

Another transistor mixer-oscillator circuit is shown in Fig. 24. This is quite an interesting circuit inasmuch as the transistor is used in both a common-base and a common-emitter circuit at the same time.

In this circuit the incoming signal induced in L3 is applied to the base of the transistor. As far as the incoming signal is concerned, the emitter is essentially at ground potential and hence the mixer operates as a common-emitter mixer.

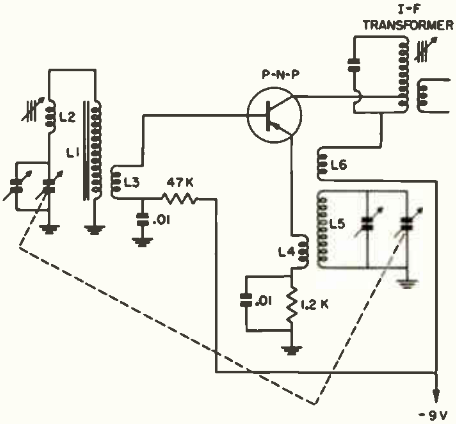


Fig. 24. Converter stage using one transistor connected in a common-base circuit for the oscillator signal, and a common-emitter circuit for the rf signal.

The oscillator signal, on the other hand, is coupled to the feedback winding L4 in the emitter circuit. Therefore, as far as this signal is concerned, the base is the common element and the oscillator operates as a common-base circuit. In spite of the fact that the two signals are fed into different elements of the transistor, mixing still takes place because of the non-linear characteristic of the emitter-base junction.

SUMMARY

The circuits we have studied in these two sections of this lesson are basic transistor circuits. Transistors are found in circuits other than these. Other common circuits in which transistors are found are multivibrators and switching circuits such as used in electronic equipment. However, the circuits that we have studied in this section are what might be considered basic circuits; you should learn these circuit configurations before going on to more complex circuits.

Do not expect to remember what these circuits look like simply by taking a quick look at the diagram in the lesson texts. You should take the time to draw each of these circuits yourself. Draw a circuit two or three times, copying it from the book, then close the book and try to draw it yourself. The chances are that the first time you try to do this you will find that you cannot reproduce the circuit, but after two or three attempts you should be able to do so. Knowing what these basic circuits look like will be a big help to you. You might not understand what all the parts are used for at this time, but we are going to study all of these circuits again in later lessons. If you are familiar with the general circuit configuration, it will be a big help to you because you will know what the circuit looks like and hence will be ready for the next step, that of learning what each and every part in the circuit is used for.

SELF-TEST QUESTIONS

(ag) In the circuit shown in Fig. 16, why is the emitter-base forward bias considerably less than the battery voltage?

(ah) Why is it necessary to provide bias stabilization in transistor amplifiers?

(ai) What advantage does the common-base amplifier circuit offer over the common-emitter circuit?

(aj) In an i-f amplifier such as the one shown in Fig. 20, why is the secondary of the input i-f transformer untuned and shown as having fewer turns than the primary winding?

(ak) What is the purpose of connecting the collector in the transistor circuit shown in Fig. 20 to a tap on the primary winding of the output i-f transformer?

(al) How are the effects of collector-base signal feedback eliminated in transistor amplifiers?

(am) What type of circuits are used in the converter stage shown in Fig. 24?

A Typical Transistor Receiver

One important use for transistors is in portable receivers. Transistors are ideally suited for portable equipment because of their small size and modest current and voltage requirements.

A typical portable receiver is shown in Fig. 25. This receiver uses circuits similar to those you have already studied in this lesson. We will run through this receiver quickly to help you see how the various stages you studied are used together in a complete receiver.

For the purpose of study, we will divide the receiver into two sections, the rf section and the audio section. In the rf section we will include all the stages where the signal present is not an audio signal.

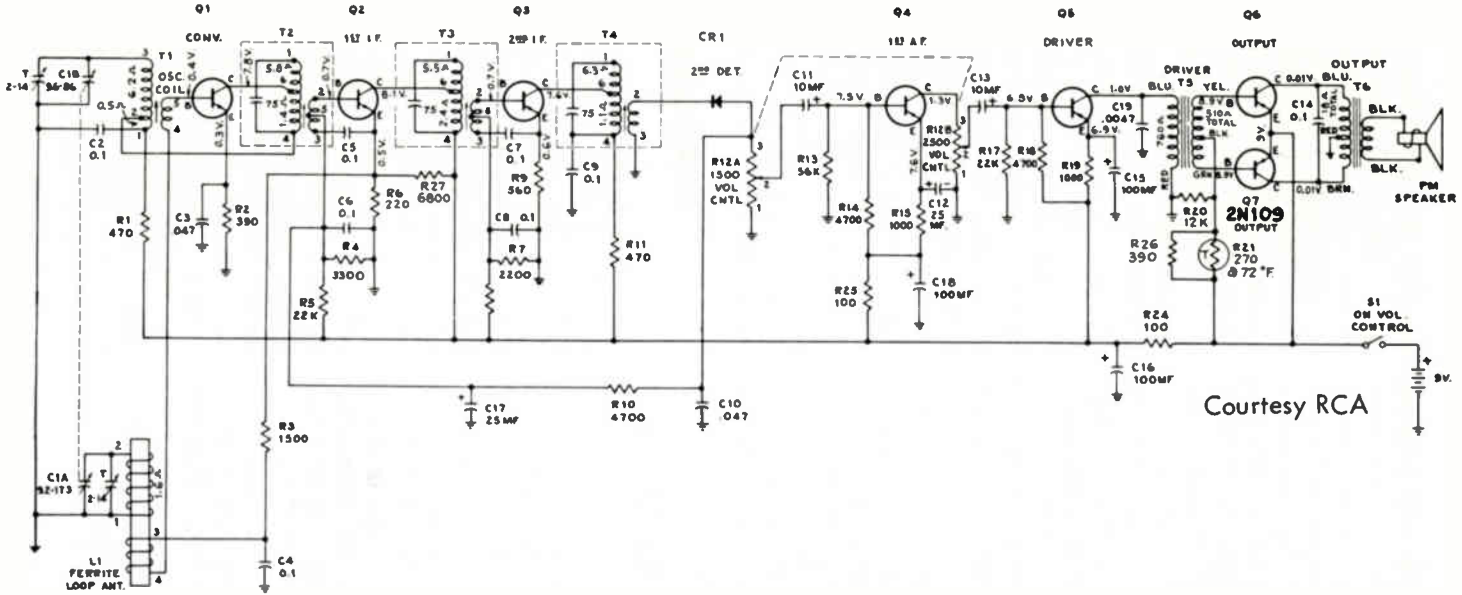
THE RF SECTION

The rf section of this receiver consists of three stages: the converter, which is actually a combination mixer and oscillator, two i-f stages, and the second detector, which is also part of the audio section. The transistors used in these stages are NPN transistors. You will remember that we can identify these transistors as NPN transistors because the arrow used to identify the emitter is pointing up, away from the base.

The converter stage in this receiver is similar to the mixer-oscillator stage shown in Fig. 23. Here we have a transistor used in a common emitter circuit performing the functions of both mixer and oscillator. The primary winding of the i-f transformer T2 is tapped, and the collector is connected to the tap. This is done to avoid loading the high Q i-f transformer and to provide maximum power transfer. Maximum power transfer can be obtained only when impedances are matched. The load impedance of this transistor is quite low, probably about 30,000 ohms, whereas that of the resonant circuit is over 500,000 ohms so the transistor collector is connected to the tap.

The i-f transformer T2 is a step-down transformer. The input impedance of the first i-f stage is very low, approximately 50 ohms. A step-down transformer is required in order to match the high-impedance primary circuit to the low-impedance secondary circuit.

The secondary of transformer T2 is tapped. The center tap, marked 5 on the diagram, is at signal ground potential because it is connected to ground through the .1-mfd capacitor C6. This capacitor is in effect a direct connection at the i-f signal frequency. Signal voltages fed from the emitter through the .1-mfd capacitor C5 will cause a current flow through the part of the secondary between terminals 3 and 5. The current flowing through this half of the secondary will set up a field which will induce a voltage between terminals 2 and 5. This voltage is applied between the base and ground and neutralizes the i-f stage. This voltage applied between the base and ground because of the signal fed back through C5 is out-of-phase with the signal voltage fed from the collector through the transistor back to the base, so the two signals cancel.



Courtesy RCA

Fig. 25. Schematic diagram of a complete portable radio using transistors in all stages.

Both transistors used as i-f amplifiers are connected in common-emitter circuits, and the collector is connected to a tap on the i-f transformer to avoid loading the transformer. The second i-f amplifier is neutralized by the signal fed through the .1-mfd capacitor C7 back to the secondary of the i-f transformer T3.

The forward bias needed across the emitter-base junction is developed by the resistors in the emitter circuit. R2 develops the voltage needed for the converter, and R6 and R9 develop the voltages for the two i-f stages.

The last i-f transformer T4 is a step-down transformer, and the secondary of this transformer is connected to a diode second detector. This diode rectifies the rf signal so that the audio signal appears in the diode output across the 1500-ohm volume control R12A.

THE AUDIO SECTION

The audio section of this receiver is made up of three stages. A PNP transistor is used in a common-emitter circuit as the first audio frequency amplifier. The circuit used in this stage is similar to the audio amplifier you already studied.

The second audio stage is called the driver stage on the schematic diagram. It is called a driver because it is a power amplifier. It is used to supply power to the push-pull output stage. The push-pull output stage in this receiver uses two transistors in a common-emitter circuit. This stage is a class B push-pull amplifier. It is somewhat different from the class A driver used in the preceding stage. In a class A stage, the average collector current does not change when a signal is applied to the input, but in a class B stage the collector current increases appreciably when the signal is applied. A class B transistor stage, like a class B tube stage, is biased to cut-off. In a transistor circuit this means that there is little or no forward bias across the emitter-base junction.

Notice the resistor R21. The symbol used to identify this resistor is that of a conventional resistor with a circle drawn around it and the letter T inside the circle. This is a thermistor. You will remember that a thermistor is a resistor with a negative temperature coefficient. In other words, if the temperature increases, its resistance decreases. Thermistors are used in this circuit to avoid instability in the output stages which temperature changes would otherwise produce.

SUMMARY

We do not expect you to remember all the circuits used in this receiver. The purpose of presenting this schematic diagram is to give you a general idea of how the various circuits you studied in this lesson may be used together in a complete portable receiver. These circuits are typical of those that you will find in portable radio receivers. In the output stages of some receivers there is only a single transistor instead of the two transistors in the push-pull circuit found in this receiver. You will also find some portables with only one i-f stage. Of course a receiver with a single i-f stage will not have the sensitivity of this receiver.

Spend some time studying this schematic diagram; it will help you become familiar with transistor circuits. This will be a big help to you in later lessons when you study these circuits in more detail.

LOOKING AHEAD

In the next group of lessons you are going to study the various types of circuits found in modern electronic equipment. Your next lesson discusses power supplies.

Power supplies are important because they are found in every piece of electronic equipment. In portable equipment the power supply is usually made up of one or more batteries. In equipment designed to operate from the power line, the power supply will often contain a transformer designed either to step-up or to step-down the power-line voltage. In addition it will contain a rectifier designed to change alternating current to direct current and then some means of smoothing out the pulsating direct current at the output of the rectifier into smooth dc. The power supply will often consist of one or more voltage-divider networks designed to provide more than one operating voltage from a single power supply.

In the lesson on power supplies and in the following lessons we will discuss the circuit in general terms first, pointing out what the circuit must do, what is needed to accomplish the desired results, what the basic circuit looks like, and some of the more important variations of the basic circuit. Then we will go into typical circuits; where possible we will give part values and other pertinent information that might help you become more familiar with these circuits. In the following lessons you will find that you will use many of the basic fundamentals studied in the first thirteen lessons. Do not fail to review these early lessons. It is a good idea to review one or two of your earlier lessons with each new lesson you study. By doing this you will pick up many of the fine points you missed the first time you went over the lesson and, in addition, you will be sure that you do not forget what you have already learned.

ANSWERS TO SELF-TEST QUESTIONS

(a) No. In the common-base circuit the collector current is always less than the emitter current because part of the emitter current leaves the transistor through the base. Although this current is quite small, it does subtract from the emitter current. Therefore the collector current will be less than the emitter current and the current gain of the stage will be less than one.

(b) They are in phase.

(c) Holes.

(d) We can obtain a voltage gain in a common-base amplifier because the output load resistor can be made quite large. Thus, even though the signal current flowing through the load resistor is smaller than the input signal current, the fact that the output load resistor can be made many times the input impedance of the transistor results in the output voltage being greater than the input signal voltage. The output voltage will be the product of the output signal current times the load resistor. The input voltage is equal to the product of the input signal current times the input resistance. As long as the output product is greater, we will have a voltage gain.

(e) A very low input impedance; high output impedance.

(f) To the grounded grid vacuum tube circuit.

(g) Yes. In the common-emitter circuit the signal voltage is applied across the input resistor. None of the emitter current that is flowing to the collector flows through this resistor. The actual signal current flowing in the input is comparatively small. At the same time, the collector current is equal to the emitter current minus any current lost in the base and therefore is much larger than the signal input current. As a result, a current gain is possible with the common-emitter circuit.

(h) The amplified signal voltage is many times the input signal voltage and is 180° out-of-phase with it in the common-emitter circuit.

(i) The input impedance of the common-emitter circuit is much higher than the input impedance of the common-base circuit.

(j) See Fig. 7A for the common-emitter circuit using an NPN circuit and Fig. 7B for a circuit using a PNP transistor.

(k) The common-emitter circuit can be compared with the tube circuit in which a tube is used in a typical grounded-cathode circuit.

(l) The output signal voltage will be in phase with the input signal voltage.

(m) The voltage gain of a common-collector circuit is less than one.

(n) The common-collector circuit has a comparatively high input impedance and a low output impedance. Its input impedance is higher than that of the other two circuits, and at the same time, it is the only circuit in which the output impedance is lower than the input impedance.

(o) The grounded plate or cathode follower circuits.

(p) The common-base circuit and the common-collector circuit.

(q) The common-emitter circuit.

(r) The common-base circuit and the common-emitter circuit.

(s) The common-emitter circuit and the common-collector circuit.

(t) The common-emitter circuit and the common-collector circuit.

(u) The common-collector circuit.

(v) Emitter current I_E; collector current I_C; and base current I_B.

(w) I_{CBO} is the symbol used to represent the collector-base reverse current with the collector-base junction reverse biased and the emitter open.

(x) The symbol V is widely used to represent voltage. The capital C and the capital E have been used to represent the collector and emitter under dc conditions. Therefore, the symbol V_{CE} means the dc collector-to-emitter voltage.

(y) The Greek letter α represents the current gain of a transistor in a common-base circuit.

(z) The maximum value that α can have will be some value slightly less than one. The current gain of the transistor in a common-base circuit will always be less than one. This is due to the fact that the emitter current will be greater than the collector current because some of the carriers leaving the emitter are lost in the base and do not reach the collector.

(aa) The forward current-transfer ratio is the gain of the transistor in a common-base circuit and hence it is equal to α.

(ab) The Greek letter β.

(ac) The alpha cut-off frequency is the frequency at which the current gain of a transistor in a common-base circuit drops to .707 of its gain at lower frequencies.

(ad) It is the frequency at which beta drops to one.

(ae) .96.

We find the value of α by using the formula

$$\alpha = \frac{\beta}{1 + \beta}$$

substituting 24 for β, we get:

$$\alpha = \frac{24}{1 + 24} = \frac{24}{25}$$

$$\begin{array}{r} .96 \\ 25\overline{)24.0} \\ \underline{225} \\ 150 \\ \underline{150} \end{array}$$

$$\alpha = .96$$

(af) Beta equals 99.

We find the value of β by using the formula

$$\beta = \frac{\alpha}{1 - \alpha}$$

substituting .99 for α, we get:

$$\beta = \frac{.99}{1 - .99} = \frac{.99}{.01}$$

$$\beta = \frac{99}{1} = 99$$

(ag) The forward bias across the emitter-base junction is equal to the battery voltage less the voltage drop across R1. There will be a substantial voltage drop across R1 because electrons leaving the base of the transistor flowing through this resistor will develop a voltage drop which subtracts from the battery voltage. Even though the current flowing through the resistor is small, the resistance of the resistor is large so that the net forward bias across the emitter-base junction is only a few tenths of a volt.

(ah) Bias stabilization is necessary because reverse collector-base current due to minority carriers crossing from the collector into the base will effectively reduce the base current. This will reduce the voltage drop across the base resistor and increase the forward bias on the transistor. The increased forward bias may cause sufficient current to flow through the transistor to destroy the transistor.

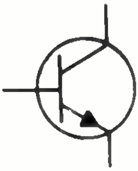
(ai) The common-base amplifier circuit provides voltage amplification without a phase shift. In some applications, particularly in television receivers, this may be an advantage.

(aj) The low input resistance of a transistor would load a resonant circuit and thus reduce the selectivity of the circuit. By using an untuned secondary and a step-down transformer, the effects of loading on the resonant circuit can be eliminated.

(ak) The collector is connected to a tap on the transformer to eliminate the effect of loading on the tuned circuit, which will cause poor selectivity.

(al) By neutralization - that is, feeding a signal equal to but 180° out-of-phase with the collector-base feedback signal back into the base circuit so that the signal deliberately fed back cancels the signal fed back through the transistor itself.

(am) The oscillator circuit uses a common-base circuit; the signal rf circuit uses a common-emitter circuit. The two circuits are used with the single transistor used in the converter stage.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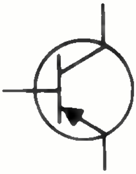
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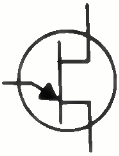

UNIJUNCTION


DIODE


ZENER DIODE

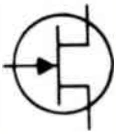

FOUR LAYER DIODE

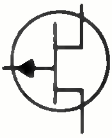

SILICON CONTROLLED SWITCH (SCS)


TUNNEL DIODE


DIAC

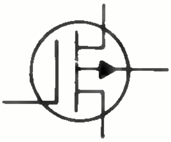

SILICON CONTROLLED RECTIFIER (SCR)


N CHANNEL JUNCTION FET


P CHANNEL JUNCTION FET


TRIAC


GATE TURN OFF RECTIFIER (GTO)


P CHANNEL DEPLETION MOSFET

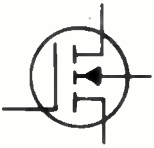

N CHANNEL ENHANCEMENT MOSFET

Table I. Semiconductor device symbols.

Lesson Questions

Be sure to number your Answer Sheet B113.

Place your Student Number on every Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time, or you may run out of lessons before new ones can reach you.

1. In a PNP transistor circuit, is the collector made (a) positive or (b) negative with respect to the base?

2. Name the three basic transistor circuits and tell what vacuum-tube circuit each one resembles.

3. Which basic transistor circuit produces a 180° phase shift?

4. Which of the following transistor amplifiers has a current gain? (a) common-base or (b) common-emitter?

5. Which basic transistor circuit has the highest input resistance?

6. (a) What does the term "alpha" applied to a transistor mean? (b) What does the term "beta" mean?

7. If the alpha of a certain transistor is .96, find the beta of the same transistor.

8. If the beta of a certain transistor is 49, find the alpha of the same transistor.

9. In the circuit shown in Fig. 16, the transistor will be very sensitive to temperature changes. How can this be overcome?

10. If a transistor has an alpha cut-off frequency of 100 kc, is it suitable for use as a 455 kc i-f amplifier?

FIRST IMPRESSIONS

First impressions mean a lot in this busy world. An applicant for a job has a pretty tough time making the grade if his appearance and first few words do not make a favorable impression on the employment manager. A salesman likewise gets the "cold shoulder" if there is anything about him which annoys the prospect.

With technical material of any kind, however, first impressions can be very treacherous. Oftentimes a simple technical book will contain a number of apparently complicated diagrams, charts, graphs, sketches or tables. Since we glance mostly at illustrations when inspecting a book, we are apt to get a misleading impression. Also, paragraphs, pages or entire lessons may seem difficult during the first reading, but become almost magically clear during the second or third reading.

If the first impressions of a required task are favorable, fine and dandy; if unfavorable, don't be discouraged, but wade right into the work and give it a chance to prove that first impressions don't always count.

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STUDY SCHEDULE

☐ **1. Introduction . . . . Pages 1-2**

The basic purpose of a power supply is discussed.

☐ **2. Rectifier Circuits . . . . Pages 3-12**

You learn about half-wave, full-wave, and bridge-type rectifier circuits using both vacuum-tube and selenium rectifiers.

☐ **3. Filter Circuits . . . . Pages 13-25**

In this section we take up capacitor filters, R-C filters, L-C filters, and choke input filters, and learn what factors affect the output voltage of a filter network.

☐ **4. Typical Power Supplies . . . . Pages 26-37**

You study ac-dc supplies, full-wave power supplies, and high-voltage supplies.

☐ **5. Answer Lesson Questions.**

☐ **6. Start Studying the Next Lesson.**

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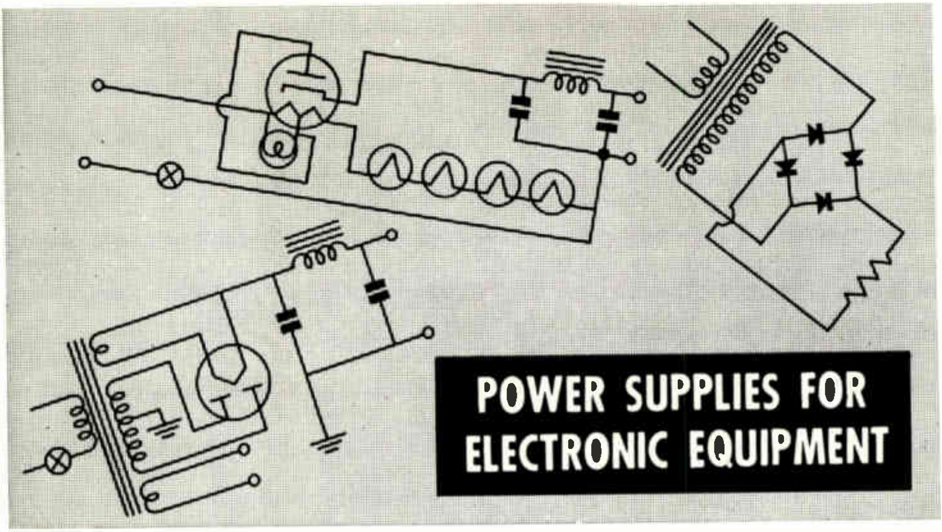

POWER SUPPLIES FOR ELECTRONIC EQUIPMENT

One of the most important sections in electronic equipment is the power supply. It is the section that furnishes the operating voltages and currents required by the various stages. If the power supply is not operating properly, the equipment can't do the job it's supposed to do.

In your career as an electronics technician, you will encounter many different types of power supplies. In equipment using tubes you will find power supplies that must supply the heater voltage for the various tubes and, in addition, a dc supply voltage that is often considerably higher than the power line voltage.

On the other hand, the power supply in transistorized equipment will be quite different from that used in tube-operated equipment. Most power supplies in transistorized equipment will have to reduce the voltage to some value less than the line voltage.

However, the current requirements of the power supply in a transistorized piece of equipment may be considerably higher than those of a power supply in a similar tube-operated device. All power supplies have basically the same function, regardless of the parts and circuitry used to make them; the power supply must supply the operating voltages and currents required by the various stages in the equipment.

You have already studied the basic components used in power supplies. In this lesson you will learn more about these components and how they are used together in this particular application. You will be introduced to some new circuits and will learn enough about power supplies to enable you to understand the purpose for which each part in a power supply is used. Once you know why the various parts are used and understand what each one is supposed to do, you should be able to service any power supply defect you encounter.

We will first take up the different rectifier circuits used in modern power supplies. The power supplied by power companies for home and industrial use is ac power, whereas the tubes and transistors used in electronic equipment require dc operating voltages. Therefore, in a power supply designed to operate from a power line, we must have some means of changing the ac to dc. The device used to do this is called a rectifier.

Once the ac is changed to dc by a rectifier, we have what is called a pulsating dc at the output of the rectifier. This is actually dc with ac superimposed on it. A power supply must therefore have some means of filtering or smoothing the pulsating dc to get pure dc. This is done by means of a filter network, which separates the ac and dc components of the pulsating dc at the rectifier output so that only the dc appears at the output of the filter network.

Many power supplies also have some type of voltage-divider network. Such a network is designed to provide several different operating voltages from one power supply. All the tubes or transistors in a piece of electronic equipment may not require the same operating voltage. It is more economical to use a single power supply and a voltage divider than to use a separate power supply for each voltage needed.

The power supplies in modern electronic equipment use solid state rectifiers in most low-voltage applications. Vacuum tubes are seldom used today as rectifiers in such devices as radio or television receivers or in other modern equipment. However, there are still millions of radios and television receivers in use today that do use vacuum-tube rectifiers. Therefore, you will probably have to work on this type of power supply as a service technician even though it is obsolete as far as its use in new equipment is concerned and you still should know how this type of rectifier works. For this reason, we will cover not only the new rectifier circuits using solid state rectifiers, but also a number of the older frequently-used rectifier circuits using vacuum tubes.

Rectifier Circuits

Any device that will pass current in one direction but not in the other direction can be used as a rectifier. You have already seen one example of this type of device: the vacuum tube. In a vacuum tube, as long as the voltage applied to the plate is positive with respect to the voltage applied to the cathode, the current will flow from the cathode to the plate of the tube. However, if the voltage applied to the plate is negative with respect to the voltage applied to the cathode, there will be no current flow through the tube because current cannot normally flow through the tube from the plate to the cathode. Thus, a two-element or diode tube was used for many years as the rectifier in the power supply of radio and television receivers.

The diode tube is entirely satisfactory as a rectifier, but it does have one big disadvantage. In order to handle the currents required in large radio receivers or in television receivers a rectifier tube with a rather heavy cathode or filament is required. Considerable power must be applied to the heater to heat the large cathode or filament, thereby bringing it to the temperature required for it to emit an abundant supply of electrons. Not only does this increase the power consumed by the equipment; also, a substantial amount of heat is given off by the diode and this, in turn, heats up other parts in the equipment. This often contributes to a shortened life of the other parts.

As we mentioned, diode vacuum tubes were used for many years as the rectifiers in radio and television receivers. However, a number of years ago the selenium rectifier began to replace the vacuum tube as the rectifier in entertainment-type equipment.

A typical selenium rectifier is shown in Fig. 1. A selenium rectifier is made up of a series of selenium discs with a coating of selenium oxide on the surface of one side of each disc. Electrons can flow from the selenium to the selenium oxide quite readily, but they cannot readily flow in the other direction, from the selenium oxide to the selenium. Thus, a selenium rectifier permits current to flow through it in one direction, but offers a high resistance to current flow through it in the opposite direction.

This type of rectifier is often called a dry-disc rectifier: "dry" to distinguish it from earlier rectifiers that used a wet chemical solution, "disc" because it is made up of discs. The square plates that are visible in Fig. 1 are cooling fins. The discs used are usually round and are

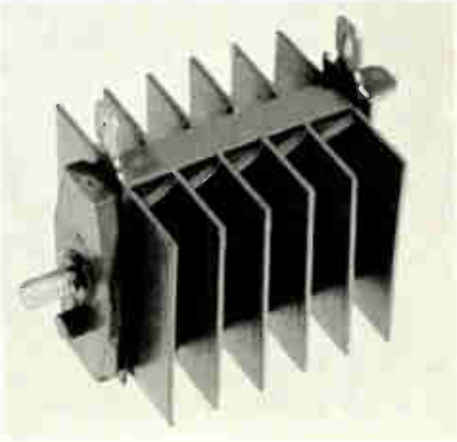

Fig. 1. A typical selenium rectifier designed for use in electronic equipment.

placed between the cooling fins, which are necessary because the rectifier does have some resistance and the current flowing through this resistance produces heat which must be dissipated.

The advantage of the selenium rectifier over the diode tube is that the selenium rectifier does not have a cathode that must be heated, and hence the power required to heat the cathode is saved. In addition, the total heat dissipated into the equipment from the selenium rectifier is somewhat lower than from a tube capable of handling the same current.

Both the vacuum tube rectifier and the selenium rectifier have been replaced in modern radio and television receivers by the silicon rectifier. The silicon rectifier, like the selenium rectifier, does not require any heater power; in addition, a silicon rectifier is much smaller than a selenium rectifier. It has a much lower forward resistance; that is, it offers far less opposition to current flow through it in the forward direction than does a selenium rectifier, and at the same time it has a higher reverse resistance (in other words it will permit a smaller current to flow through it in the reverse direction than a selenium rectifier).

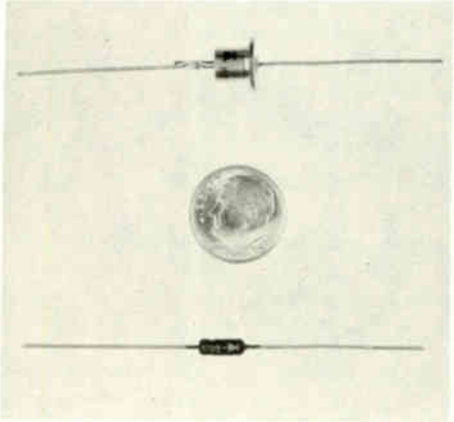

Fig. 2. Two typical silicon rectifiers with a dime between them to show their relative size.

Two typical silicon rectifiers are shown in Fig. 2. The rectifier at the top is called a top-hat rectifier because of its shape. A rectifier of this type and size is capable of handling currents several times those required in a color TV receiver. We have shown a photograph of the two rectifiers with a dime in between them so you can get an idea of the relative size of the two units. The lower rectifier is capable of handling currents of two or three amperes.

In addition to their small size and high current-handling capabilities, silicon rectifiers have another big advantage over selenium and vacuum tube rectifiers due to modern manufacturing techniques: they are relatively inexpensive to manufacture. Furthermore, unless they are overloaded, their life is almost indefinite.

Now, let's see how the various types of rectifiers are used in power supply circuits.

HALF-WAVE RECTIFIERS

You already know that the power supplied by most power companies is ac power and that the voltage supplied has a waveform that is called a sine wave. A typical single cycle is shown in Fig. 3A. A rectifier circuit using a diode tube is shown in Fig. 3B. Let's assume that the waveform shown at A represents the voltage at terminal A of Fig. 3 with respect to the voltage at terminal B. This means that for the first half-cycle (that is, the voltage waveform

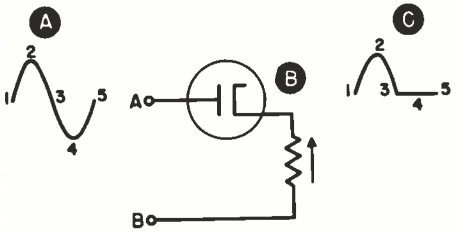

Fig. 3. How current flows in a half-wave rectifier circuit for one ac cycle. We have omitted the rectifier heater to simplify the diagram.

from point 1 to point 3), the plate of the tube will be positive. When the plate of the tube is positive, it will attract electrons from the cathode; therefore, current can flow through the tube.

Thus during the first half-cycle, as the plate voltage starts at point 1 and builds up to point 2, the current through the tube will increase from point 1 to point 2 as shown in Fig. 3C. As the voltage decreases during the first half-cycle from point 2 to point 3, the current through the tube will decrease as shown from point 2 to point 3 in Fig. 3C. When the voltage in Fig. 3A reaches point 3 there will be zero potential between points A and B in the rectifier circuit and current will stop flowing.

During the next half-cycle terminal A will be negative with respect to terminal B. This means that the plate of the tube will be negative; hence no current can flow through the tube. Therefore, the current will be zero (as shown in the waveform in Fig. 3C) as the voltage swings from point 3 to point 5.

The rectifier circuit shown in Fig. 3 conducts when the plate of the tube is positive. Since this occurs during one half the time of each cycle then the rectifier conducts during one half of the cycle but not during the other half. As a result, the rectifier is called a half-wave rectifier. If we operate this type of rectifier from a 60-cycle power line, we will get 60 current pulses through the rectifier during one half-cycle and 60 intervals during which there is no current flow through the rectifier.

Another half-wave rectifier is shown in Fig. 4. Here we have shown a solid-state rectifier in place of the tube. This could be either a selenium rectifier or a silicon rectifier -- the same symbol is used for both types.

Notice the schematic symbol used for the rectifier. Also notice that the arrows indicate that the direction of current flow through the circuit is opposite to the direction in which the arrow points in the schematic symbol. The reason for this is that in the early days of electricity, scientists thought that current flowed from positive to negative. Therefore, this symbol was designed to show the direction in which current flowed. But it was discovered later that current flow was actually electron flow and that it flowed from negative to positive, a direction opposite from that in which the early scientists thought it flowed. Although we know current flow is from negative to positive, we still use the same symbol; it has never been changed so that the arrow is actually pointing in the direction opposite to the direction of electron flow.

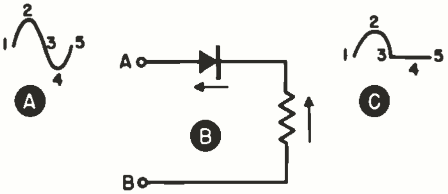

Fig. 4. A half-wave selenium rectifier circuit.

In a power supply of this type using a selenium rectifier, with terminal A positive with respect to terminal B, the selenium rectifier will offer only a low resistance to the flow of current through it; therefore, current flows in the circuit from B through the load and through the rectifier and back to terminal A. During the next half-cycle, when terminal A is negative with respect to terminal B, the selenium rectifier will offer a very high opposition to the flow of current through it so that there will be little or no current flow through the load (as shown in Fig. 4C).

We mentioned that the schematic symbol for the rectifier in Fig. 4 also represents a silicon rectifier. If a silicon rectifier is used, the rectifier will simply consist of a PN junction. The P-type material will be on the side represented by the arrow and the N-type material by the flat line. With a PN junction rectifier in the circuit when terminal A is positive and terminal B is negative, we will have a positive voltage applied to the P side of the junction and a negative voltage applied to the N side of the junction. The negative voltage will repel electrons from the N side of the junction across the junction into the P-type material. Electrons will be attracted through the P-type material by the positive potential applied to it. In other words, there will be a forward bias placed across the junction and current can readily flow through the rectifier because the carriers can cross the junction.

During the next half-cycle when the polarity reverses, terminal A will be negative and terminal B positive. Thus there will be a negative voltage, applied to the P side of the junction, which will repel electrons and prevent them from crossing the junction. At the same time there will be a positive voltage, applied on the N side of the junction, which will prevent any holes from the P side crossing the junction. In other words, there will be a reverse bias placed across the junction; hence the carriers cannot cross the junction and there will be no current flow through the circuit.

Of the three types of half-wave rectifiers, the silicon-type rectifier is the most widely used in modern equipment because of its small size, low cost and very low forward voltage drop.

Sometimes, in order to operate a piece of electronic equipment, a higher voltage is required than can be obtained directly from the power line. Under these circumstances a step-up transformer may be used to step up the voltage as shown in Fig. 5. The secondary-to-primary turns-ratio is simply adjusted to provide the required voltage step-up. A half-wave rectifier is then used as shown to rectify the ac and change it to pulsating dc. The operation of the half-wave rectifier is exactly the same in the circuit as

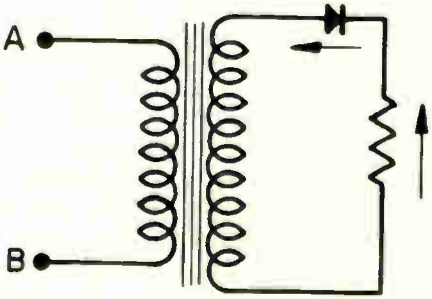

Fig. 5. A half-wave rectifier circuit using a power transformer to produce an output voltage greater than the power line voltage.

it was in the preceding circuits; however, the rectifier will have to have a higher voltage rating to make up for the fact that it is being used in a higher voltage circuit.

The disadvantage of the circuit shown in Fig. 5 is that power transformers are comparatively expensive. By means of the circuit shown in Fig. 6 a voltage approximately twice the voltage obtainable from the half-wave rectifier circuits shown in Figs. 3 and 4 can be obtained. This circuit can be operated directly from the power line and is known as a voltage-doubler circuit.

The operation of this circuit is quite simple. During one half-cycle terminal A will be negative with respect to terminal B. During this half-cycle electrons flow from A into the side of the capacitor C1 marked with the minus sign. The electrons flowing into this side of the capacitor force electrons out of the other side leaving a positive charge on this side of C1. The electrons leaving the positive side of C1 flow through the rectifier D1, back to side B of the power line which is positive and which will attract electrons. Thus, during this half-cycle, when terminal A is negative with respect to terminal B, capacitor C1 is charged with the polarity shown. The peak charge on C1 will be equal to the peak value of the ac input voltage.

During the next half-cycle, when terminal A is positive with respect to terminal B, we have a situation where the voltage between terminals A and B is effectively placed in series with the voltage charging capacitor C1. These series-connected voltages will cause a current to flow through the load and through D2. During this half-cycle terminal A is positive with respect to terminal B. This means that terminal B is negative. Electrons flow from terminal B through the load and through D2. They are attracted by a positive voltage which is equal to the voltage across C1 plus the line voltage. Thus the peak voltage that can be developed across the load will be equal to twice the peak line voltage.

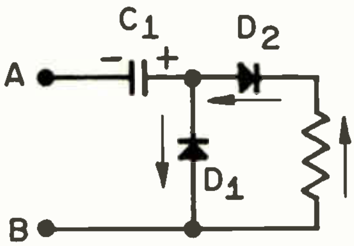

Fig. 6. A half-wave voltage-doubler circuit.

You might wonder why the current flows through only one rectifier during each half-cycle. During the first half-cycle, when terminal A is negative with respect to terminal B, the electrons flowing through D1 and charging C1 cannot flow through D2 because the diode is connected in such a way as to prevent current flow through it in that direction. Similarly, during the next half-cycle, when terminal B is negative and terminal A is positive, current cannot flow through D1 because it would have to flow through it in the reverse direction. Current can flow through the diodes only in the direction shown and it will flow through D1 during one half-cycle and through D2 during the other half-cycle.

This type of power supply is known as a half-wave doubler circuit. It is called a voltage-doubler circuit because the voltage across the load is effectively double the line voltage.

It is called a half-wave circuit because there is a current pulse to the load during only one half of each cycle. The half-wave voltage-doubler circuit is widely used in modern radio and television receivers. It's a very important circuit and you should be sure you understand how it works before leaving it.

When a half-wave rectifier is used in the power supply, the current will flow through the rectifier in a series of pulses. With a 60-cycle power supply line, there will be 60 pulses per second: one pulse during each positive-half cycle and nothing during each negative-half cycle. The net result is that you will have current flowing through the rectifier for no more than half the time. This results in a pulsating dc output from the rectifier that is rather difficult to smooth out to the pure dc required in most equipment to operate the tubes and/or transistors. A somewhat better arrangement is the full-wave rectifier that passes current during both halves of the ac voltage cycles.

FULL-WAVE RECTIFIERS

A typical full-wave rectifier circuit is shown in Fig. 7. Notice that the tube used is a twin diode tube. The tube has two plates and a single filament which is used with both plates. In operation, this tube acts as two separate diode tubes.

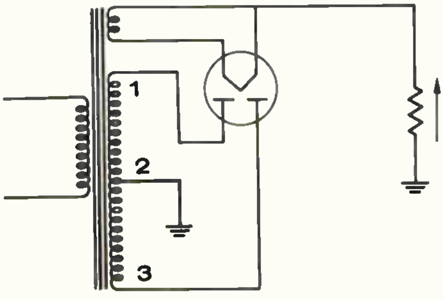

Fig. 7. A full-wave rectifier circuit using a single rectifier tube with two plates.

The power transformer used in the rectifier circuit has three windings. The primary winding is the winding that connects to the power line. A low-voltage winding is used to provide the current required to heat the filament of the rectifier tube. It serves no other purpose as far as the operation of the rectifier circuit is concerned. This winding is often referred to as the filament winding.

The high-voltage winding on the transformer is the winding that will supply the pulsating current to the load resistor. Notice that this winding has a center tap. In operation, one half of the winding first supplies the current and then, during the next half-cycle, the other half of the winding supplies current to the load.

We can see how this rectifier circuit works if we consider one half-cycle during which terminal 1 of the high-voltage secondary is positive. This means that terminal 2 will be negative with respect to terminal 1 and terminal 3 will be even more negative. Electrons will leave the center tap, terminal 2, and flow through ground to the load resistor. They will flow through the load resistor to the filament of the rectifier tube and then be attracted to the plate connected to terminal 1 because this plate has a positive voltage applied to it. No electrons will flow to the other plate because this plate is negative with respect to both terminals 1 and 2.

During the next half-cycle, the polarity of the secondary voltage will reverse. At this time terminal 3 will be positive, terminal 2 negative with respect to it, and terminal 1 even more negative. During this half-cycle electrons will leave terminal 2 and flow through ground to the load, through the load and to the filament of the rectifier tube, and then to the plate connected to terminal 3 because this plate now has the positive voltage applied to it. No electrons will flow to terminal 1 because terminal 1 is negative with respect to both terminals 2 and 3.

Notice that with the full-wave rectifier circuit we get a current pulse through the load resistor during each half-cycle. This means that for a 60-cycle power line we will get 120 pulses of current through the load. Since there is current flowing through the load during each half-cycle, this type of rectifier produces an output that is much easier to filter to a smooth dc than the output from a half-wave rectifier.

Either selenium rectifiers or silicon rectifiers can be substituted in this type of circuit in place of the rectifier tube. This type of circuit was widely used in older television receivers along with vacuum tubes. Modern TV receivers use silicon rectifiers and frequently use bridge-rectifier circuits or voltage-doubler circuits in place of this circuit.

BRIDGE-RECTIFIER CIRCUITS

One of the disadvantages of the full-wave rectifier circuit shown in Fig. 7 is that it requires a transformer with a center-tapped secondary. The total voltage across the entire secondary winding is actually twice the voltage between the center tap and either end of the secondary winding. This type of transformer is more expensive to manufacture than a transformer without a center tap because twice as many turns are required on the secondary to get the required voltage.

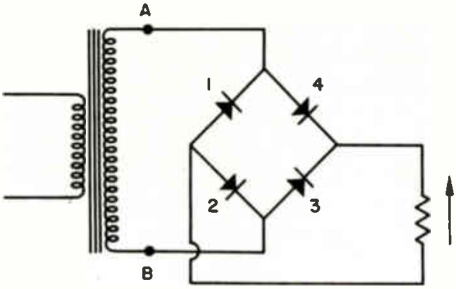

Fig. 8. A bridge-rectifier circuit.

A circuit that gets around the requirement of a center-tapped secondary is shown in Fig. 8. This is called a bridge-rectifier circuit; it is also often called a full-wave bridge-rectifier circuit because current flows to the load during each half-cycle.

A quick look at the circuit immediately shows us that four rectifiers are required in a circuit of this type. At one time this was a disadvantage because of the cost of rectifiers, but silicon rectifiers are comparatively inexpensive today and it is usually more economical to use the extra two silicon rectifiers and avoid the center tap on the secondary winding of the power transformer. The power transformer shown in Fig. 8 would be far more economical to manufacture than the one shown in Fig. 7.

The operation of the bridge rectifier is comparatively simple. When terminal A is positive and terminal B is negative, current will flow from terminal B through the rectifier marked 2 on the diagram and then through the load to the junction of rectifiers 3 and 4. It will then flow through rectifier 4 back to terminal A on the transformer. During the next half-cycle, when terminal A is negative and terminal B is positive, current will flow from terminal A on the transformer through the rectifier marked 1 on the diagram and then through the load back to the junction of rectifiers 3 and 4. This time the current will flow through rectifier 3 back to terminal B of the power transformer.

Notice that during each half-cycle current flows through two of the rectifiers. During one half-cycle it will flow through rectifiers 2 and 4 and during the other half-cycle it will flow through rectifiers 1 and 3. Also notice that current flows during both half-cycles; therefore, this bridge rectifier is a full-wave rectifier.

Bridge rectifiers have been used in television receivers where comparatively high operating voltages and high currents are required. The bridge circuit eliminates the need for the center tap on the power transformer secondary winding and thus reduces the cost of the transformer. The voltage regulation (the ratio of the full-load voltage to the no-load voltage) obtainable with this type of power supply is as good as the regulation that can be obtained from the full-wave rectifier circuit shown in Fig. 7.

FULL-WAVE VOLTAGE DOUBLERS

A full-wave voltage-doubler circuit is shown in Fig. 9. One advantage of this type of circuit is that we get the same load voltage as you have in a circuit like the bridge rectifier shown in Fig. 8, although only half as many turns are required on the secondary of the power transformer. This will result in a savings in the cost of the power transformer. Another advantage of this type of circuit is that only two rectifiers are required instead of the four required in the bridge-rectifier circuit.

The operation of the full-wave voltage-doubler circuit is quite simple. During one half-cycle terminal A of the power transformer secondary will be negative and terminal B will be positive. During this half-cycle current flows from terminal A through diode D2 to the capacitor C2 charging the capacitor as shown. Electrons flow into the negative side of the capacitor and out the positive side back to terminal B of the power transformer. During the next half-cycle, terminal B of the power transformer secondary will be negative and terminal A will be positive. During this half-cycle electrons leave terminal B of the power transformer and flow into capacitor C1. They flow into the side of the capacitor marked with the minus sign and force electrons out of the plus side. Electrons leaving the plus side flow through diode D1 back to terminal A of the power transformer, which is positive.

The capacitors C1 and C2 are connected in series and they supply the voltage to the load. The capacitors are charged by the current flowing

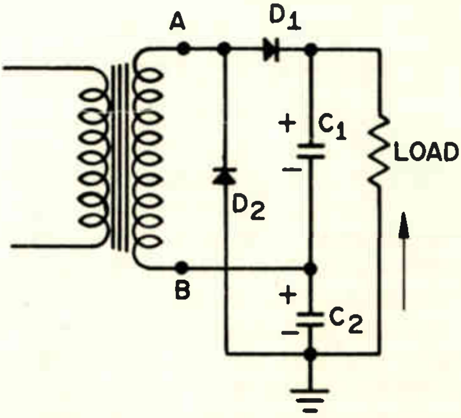

Fig. 9. A full-wave voltage doubler.

through the diodes, and since there is a charging pulse each half-cycle we will get 120 charging pulses from a 60-cycle power line. Since there is a charging pulse during each half-cycle, the circuit is a full-wave rectifier. The actual voltage that will be available across C1 and C2 in series will depend upon the power transformer secondary resistance, the resistance of the diodes when they are conducting, the size of the two capacitors, and the size of the load. As the resistance of the load increases, the current that will flow through the load decreases, and the charge on each capacitor becomes closer to the peak value of the ac voltage between terminals A and B.

Notice that in the diagram we have shown the direction of current flow through the load. The load current is supplied entirely by the charged capacitors C1 and C2. As the capacitors supply current to the load, electrons leave the negative plate of C2 and flow through the load in the direction shown. These electrons flow into the positive side of C1 forcing electrons out of the negative side into the positive side of C2. Thus the current flow through the load tends to reduce the charge across the capacitors. Of course, during each half-cycle one of the diodes conducts to build the charge across one of the capacitors up towards the peak value of the line voltage.

While this type of rectifier circuit offers some advantages over the circuits shown in Figs. 7 and 8, it does not have as good voltage regulation as they have. However, by using capacitors of large capacity for C1 and C2, and with modern silicon rectifiers that have a very low resistance when they are conducting, reasonably good voltage regulation can be obtained from this type of power supply. You will find the power supply widely used both in monochrome and color television receivers. Be sure you understand how it operates because you will run into it frequently.

In comparing this power supply with the half-wave doubler circuit shown in Fig. 6, we immediately see that the full-wave doubler circuit is best suited to equipment where a power transformer is used. The half-wave voltage-doubler circuit is widely used in equipment where no power transformer is used.

SUMMARY

The rectifier circuits that we have discussed in this section of the lesson are extremely important. As you know, the power supplied by the power companies is alternating current and the tubes and transistors in electronic equipment require direct current for their operation. Therefore, equipment designed to operate from the power line must use some type of rectifier to convert the alternating current to direct current. One of the circuits shown in this section of the lesson is likely to be found in any type of electronic equipment you will service.

The half-wave rectifier circuit shown in Fig. 5 is perhaps the most widely used. All table model radio receivers use this type of rectifier circuit without a power transformer so that the receiver can operate directly from the power line. The half-wave voltage-doubler circuit shown in Fig. 6 is widely used in television receivers where operating voltages higher than those that can be obtained directly from the power line are needed. In some of the older radio receivers and many older television receivers a full-wave rectifier circuit such as shown in Fig. 7 will be found. This type of circuit was used almost exclusively in television receivers before the development of low-cost selenium and silicon rectifiers.

The bridge-rectifier circuit shown in Fig. 8 is used in many television receivers, particularly large television receivers where fairly high voltages and high currents are required. This type of circuit is also used in some transistorized equipment where lower than line voltages are required. In this instance, instead of being a step-up transformer, the transformer will be a step-down transformer that steps the line voltage down to a low value. The bridge-rectifier circuit is then used so that good voltage regulation can be obtained and so that at the same time a comparatively large current can be taken from the power supply.

The full-wave voltage-doubler circuit has been used in many television receivers -- in those which use power transformers where voltages higher than the line voltage are required -- yet at the same time, the transformer serves primarily as an isolation transformer. In other words, the secondary voltage is approximately equal to the primary voltage. The higher voltage required is obtained by the voltage-doubling action. The output from the full-wave doubler circuit is somewhat easier to filter or smooth out than the output from the half-wave doubler circuit, because with the former we have 120 pulses per second through the load and with the latter we have only 60 pulses per second.

Before leaving this section regarding rectifier circuits, why not try to draw the circuits yourself? It would be worthwhile, and you don't have to draw them from memory -- copying them first from the book will help you to remember what they look like. Eventually, you'll be able to draw them from memory and recognize various circuits on the schematic diagram of any radio or TV receiver or piece of electronic equipment you may encounter.

After reviewing this section, do the following self-test questions.

SELF-TEST QUESTIONS

(a) In a half-wave rectifier circuit such as the circuit in Fig. 5, how many current pulses per second will there be through the load when the power line frequency is 60 pulses per second?

(b) What is the disadvantage of a half-wave rectifier circuit?

(c) What is the purpose of the diode marked D1 in the half-wave voltage-doubler circuit shown in Fig. 6?

(d) Why is the circuit shown in Fig. 7 called a full-wave rectifier circuit?

(e) What is the disadvantage of the full-wave rectifier circuit shown in Fig. 7?

(f) What are the advantages of the bridge-rectifier circuit shown in Fig. 8?

(g) What advantage does the voltage-doubler circuit shown in Fig. 9 have over the voltage-doubler circuit shown in Fig. 6?

(h) What are the advantages and disadvantages of the full-wave voltage doubler over the bridge-rectifier circuit?

Filter Circuits

The output from the rectifiers we discussed in the preceding section is not pure dc. Instead, it is pulsating dc: "direct" because it flows in only one direction, "pulsating" because it is varying in amplitude rather than flowing steadily. A pulsating dc voltage is a voltage that does not change polarity, but does change in amplitude. The voltage at the output of a half-wave rectifier will be zero during one half of each cycle and swing in a positive direction during the other half of each cycle.

Looking at the half-wave circuits shown in Fig. 3 and 4, you can consider the rectifier more or less as a switch. During one half-cycle the switch is closed so that the load is connected directly across the power line, and during the other half-cycle the switch is open so that no voltage is applied to the load. The voltage across the load in a half-wave rectifier circuit looks like Fig. 10A. The first half-cycle represents the cycle when the switch is closed and the load is connected directly across the power line, and the second half-cycle represents the cycle when the switch is open and there is no voltage applied across the load. We have shown what the voltage across the load will look like for four cycles in Fig. 10A.

In a full-wave rectifier circuit such as shown in Fig. 7, you have two switches. During one half-cycle one switch closes and connects the load across one half of the power transformer secondary; then, during the next half-cycle, the other switch closes and connects the load across the other half of the transformer secondary.

In the bridge rectifier shown in Fig. 8 two rectifiers act as switches and close to connect the load across the transformer secondary during one half-cycle; then during the next half-cycle the other two switches close, giving the effect of turning the load around so that the current flows through it in the same direction and the voltage applied across the load has the same polarity. The output from a full-wave rectifier circuit will produce a voltage across the load that looks like Fig. 10B.

As you can see from the waveforms shown in Fig. 10, the output taken directly from the rectifier is not a pure dc. There is a voltage, but the voltage drops to zero, builds up to the maximum value, and drops to zero again. In the half-wave circuit it remains at zero for a half-cycle and then builds up again in a positive direction. In the full-wave rectifier circuit the voltage builds up across the load during each half-cycle. In either case, this pulsating voltage will cause a pulsating current through the load which is entirely unsuitable for use in electronic equipment. Fortunately, there are convenient methods that can be used to filter or smooth this voltage to a pure dc voltage.

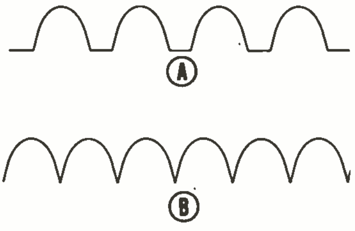

Fig. 10. Output voltage from half-wave and full-wave rectifier.

The pulsating dc voltage at the output of the rectifier is actually a dc voltage with an ac voltage, called a ripple voltage or a hum voltage, superimposed on it. The circuits used to get rid of this ripple or hum voltage are called filter circuits. There are a number of different types of filter circuits found in electronic equipment; in this section we will cover some of the circuits more commonly used.

THE SIMPLE CAPACITOR CIRCUIT

One of the simplest filters is the single capacitor filter shown in Fig. 11. In Fig. 11A we have shown a rectifier circuit using a tube and in Fig. 11B a rectifier circuit using a silicon rectifier. Notice that the circuits are practically identical -- we simply changed the rectifying devices in the two circuits.

The simple capacitor-type filter is sometimes used in circuits where the current drained or taken from the power supply is low. If the rectifier must supply high current to the circuit, this type of filter is generally unsatisfactory because there will be too much ripple or hum present across the load. In other words, the simple filter is simply not capable of eliminating all the ac or ripple voltage present at the output of the rectifier.

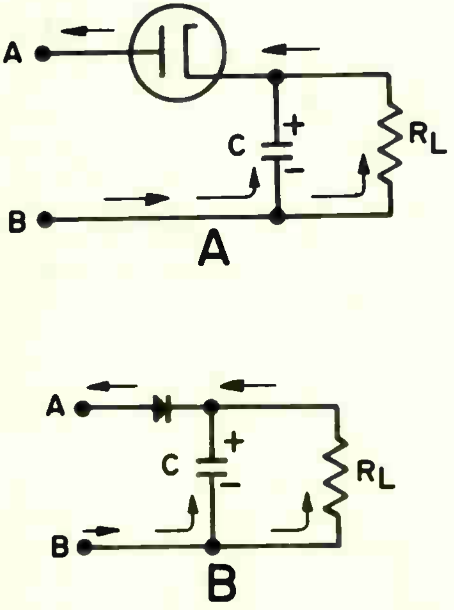

Fig. 11. A simple capacitor-type filter.

Both circuits shown in Fig. 11 work in the same way. Current flows through the rectifier during one half-cycle, as in the half-wave rectifier circuits we studied previously. When terminal A is positive, electrons will flow from terminal B through the load and through the rectifier back to terminal A. At the same time, electrons will flow into the negative side of the capacitor and out the positive side and through the tube or silicon rectifier back to terminal A. The capacitor eventually will be charged to a value almost equal to the peak line voltage. This will happen when the ac line voltage reaches its peak value with terminal A at its peak positive voltage with respect to terminal B.

Now, if the load on the rectifier circuit is light (that is, if the load resistor is a high resistance that draws very little current), as the ac input voltage between terminal A and B drops, capacitor C will begin to supply the current required by the load. Electrons will start to leave the negative side of the capacitor and flow through the load resistor back to the positive side of the capacitor. They will continue doing this as the ac voltage drops to zero and remains at zero during the next half-cycle and starts to build up again in the positive direction. The capacitor will continue to supply current to the load as long as the voltage across the capacitor is greater than the ac input voltage. Eventually, the input voltage will reach a value greater than the capacitor voltage; then we'll get a current flow into the capacitor and through the rectifier to recharge the capacitor.

In Fig. 12 we have shown the ac input voltage. Notice that during the first half-cycle between points 1 and 2 in Fig. 12A the ac voltage is increasing in a positive direction. Let's assume that terminal A in Fig. 11 is becoming positive with respect to terminal B. This explanation applies to both of the two circuits shown. During this first half-cycle the capacitor is charging and follows a curve as shown from point 1 to point 2 in Fig. 12B. Now, as the ac cycle drops from point 2 to point 3 on curve A in Fig. 12, the voltage drops faster than the capacitor discharges. During the interval from point 2 to point 5 and almost to point 6, as shown in Fig. 12A, the capacitor discharges very little. The discharge is shown on the curve from point 2 over to the number 5 on curve B. At this point the ac input voltage exceeds the capacitor voltage, so the capacitor is recharged again.

In circuits where the drain or load current is low, the capacitor will discharge very little between current pulses that recharge it so that the voltage across the capacitor and hence the voltage across the load remain almost constant. Of course, as the requirements of the load increase, the capacitor will discharge more so that there will be more of a voltage drop across the capacitor and across the load than in circuits where current drain is low.

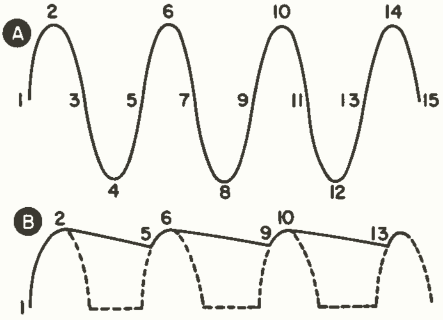

Fig. 12. Voltage waveshapes for a simple capacitor filter. (A) Input voltage; (B) output voltage.

There are several important points you should notice in the circuits shown in Fig. 11. Notice that the current does not flow during an entire half-cycle, but flows only when the line voltage exceeds the voltage across the capacitor. This may be for a very short interval if a load is a high resistance and draws very little current, or it may be for a sizable portion of a half-cycle if the load is a low resistance and draws a high current from the power supply. However, since the current flows through the rectifier in pulses, then the current pulse through the rectifier must be many times the average dc current flowing through the load. This is because the pulse or current that flows through the rectifier during the interval in which the rectifier is conducting must supply enough current to the capacitor to charge the capacitor and make up for the current it is going to supply for the remainder of the cycle.

When the rectifier is not conducting it is because the voltage across it is what we call a reverse voltage. In other words, it has a polarity opposite from that which the rectifier needs to conduct. In the case of the vacuum tube circuit this means that the plate of the tube is negative with respect to the cathode; in the case of the silicon rectifier, that there is a reverse bias across the junction.

One of the important characteristics of a rectifier is the maximum peak reverse voltage that can be placed across the rectifier before it breaks down. In the circuit shown in Fig. 11 the capacitor will be charged as shown and the charge can equal the peak line voltage. During the next half-cycle, when the polarity of the input voltage reverses, terminal A will be negative and terminal B will be positive. When this voltage reaches its peak, the peak reverse voltage across the rectifier will be equal to twice the peak line voltage. The rectifier must be able to withstand this voltage without breaking down. This important characteristic, by which rectifiers are rated, is usually referred to as "PRV" (peak reverse voltage), although it may also be called "PIV" (peak inverse voltage). The two are simply the maximum reverse or inverse voltages that can be applied across the rectifier without its breaking down. In circuits such as those shown in Fig. 11, the PIV should be considerably higher than twice the peak line voltage in order to allow a reasonable safety factor.

As we mentioned previously, the simple capacitor-type filter shown in Fig. 11 is usable only where a small current is required by the load. If the current required is small, the output capacitor can be made large enough so that it discharges very little between pulses. If the current required by the load is high, on the other hand, then the capacitor will discharge appreciably between charging pulses, resulting in a varying voltage applied to the load. This is essentially the same as applying dc mixed with ac to the load. Additional filtering is required in applications of this type in order to eliminate ac so that we will have pure dc across the load.

AN R-C FILTER

An improved filter, which is often called a pi filter because it looks like the Greek letter pi (π), is shown in Fig. 13. You will notice that this filter consists of two capacitors, C1 and C2, and a filter resistor, R1.

The operation of the half-wave rectifier and capacitor C1, which is called the input filter capacitor, is the same as in the simple capacitor filter shown in Fig. 11. The rectifier tube passes current pulses to charge capacitor C1 with the polarity indicated on the diagram. However, if the

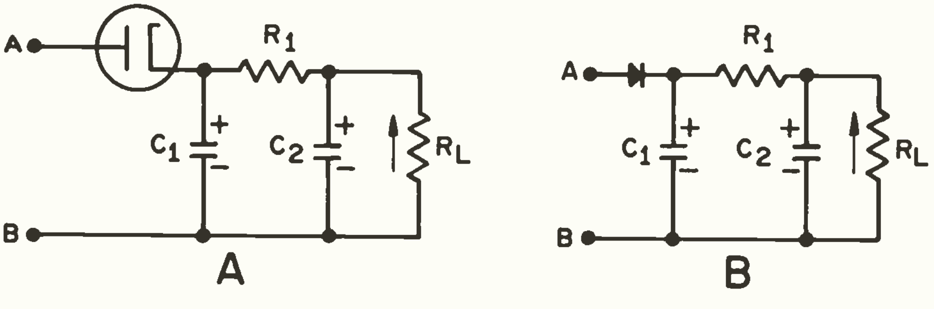

Fig. 13. An R-C pi-type filter.

load resistance R_L is low enough to draw appreciable current from the supply, then the voltage across C1 will discharge appreciably during the portion of the cycle when the rectifier tube is not conducting. Thus, we have dc with an ac superimposed on it across C1.

Now, to see the action of R1 and C2, let us first consider how the capacitor C2 reacts to ac and to dc. Remember that a capacitor is a device that will not pass dc -- it can be charged so that a dc voltage will exist across it, but applying dc to the plates of the capacitor will not cause a current to flow through it. Although electrons cannot cross through the dielectric of a capacitor, however, applying ac to the dielectric of a capacitor yields the effect of a current flowing through it. This is due to the fact that electrons will flow first into one plate and then into the other as the polarity of the ac voltage reverses.

You will remember from your study of capacitors that a capacitor offers what is called capacitive reactance (or opposition) to the flow of ac through it. The exact reactance that any capacitor will offer to the flow of ac through it is given by the formula:

$$Xc = \frac{1}{6.28 \times f \times C}$$

You can see from this formula that the larger the value of the capacitor, the lower the capacitive reactance will be to an ac voltage of a particular frequency. In Fig. 14A we have shown how the filter consisting of R1 and C2 reacts to dc; in Fig. 14B, we have shown how it reacts to ac.

As you know, a "perfect" capacitor will not pass dc -- although no capacitor is really perfect because there will always be a small dc current (called a leakage current). In other words, the capacitor offers a very high resistance to dc, so we have shown it as resistor R_{c2}. Most of the dc voltage applied to the input of this filter network will appear across the capacitor, and there will be very little dc dropped across the resistor R1. The exact drop across this resistor will depend upon the size of the resistor and the current drawn by the load.

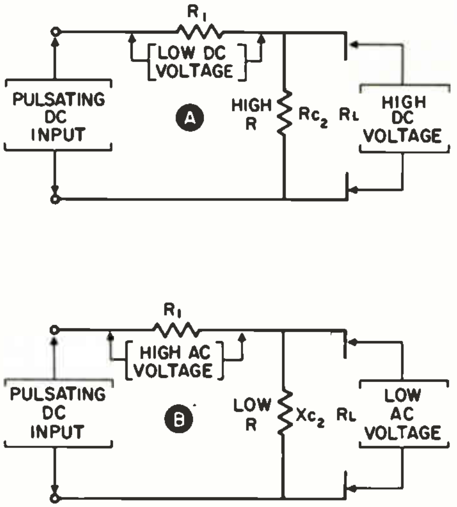

Fig. 14. Equivalent circuits showing the reaction of an R-C filter to dc at A, and to ac at B.

Now look at Fig. 14B which shows the reaction of the circuit to an ac voltage. The capacitor has a very low reactance to ac, so most of the ac voltage will be dropped across R1, because the resistance of R1 is much higher than the reactance (X) of C2. R1 and C2 act as a voltage divider network with most of the ac being dropped across R1 because its resistance is much higher than the reactance of C2.

There is another way of looking at this type of power supply which may help you see exactly what is happening in the circuit. Refer back to Fig. 13; the explanation applies to the circuit using the vacuum tube rectifier shown at A and to the one using the silicon rectifier shown at B.

When terminal A is positive with respect to terminal B, the diode will conduct and current can flow through the diode and through the load. During this part of the cycle electrons will flow into the plates of C1 and C2 marked with a minus sign. At the same time electrons will flow out of the other plate of both capacitors. Electrons leaving the positive side of C1 will flow directly through the diode being attracted by the positive voltage at terminal A. Because the resistance of the rectifier is low, C1 can charge up to a value almost equal to the peak ac voltage. However, the electrons leaving the positive side of C2 must flow through the filter resistor R1. Thus, capacitor C2 cannot charge to as high a voltage as capacitor C1.

When the ac input voltage drops so that the diode no longer conducts, capacitors C2 and C1 begin supplying the power required by the load. However, capacitor C1 is charged to a higher voltage than capacitor C2. Hence, capacitor C1 begins supplying power to the load and also tries to charge capacitor C2. Since electrons flowing from the negative side of C1 to the positive side must flow through filter resistor R1, the attempt of these electrons to charge C2 and flow through the load resistor will be somewhat restricted by R1. The net effect is that the resistor R1 prevents C2 from charging to as high a peak voltage as it would if R1 were not on the circuit. Because C1 charges to a higher voltage than C2, and while discharging tends to charge C2, the voltage across C2 is more nearly constant than the voltage across C1.

AN L-C FILTER

The disadvantage of the resistor-capacitor type of filter shown in Fig. 13 soon becomes apparent if you consider the size of the resistor and capacitor needed to obtain effective filtering and also the effect that the high value of resistance in the circuit has on the dc voltage present.

Consider Fig. 13 again for a minute. Suppose that the ac component of the pulsating dc across C1 is 10 volts and that the maximum ac component that can be applied to the load is only 1 volt. This means that the filter network consisting of R1 and C2 must produce a 9-to-1 voltage division. In other words, of the 10 volts ac appearing across C1 we must drop 9 volts across R1 and 1 volt across C2. This means that the resistance of R1 must be about 9 or 10 times the reactance of C2.

A 25-mfd capacitor (which is fairly large, particularly if it must be built to withstand high voltages), has a reactance of about 100 ohms at a frequency of 60 cycles. If we used such a capacitor for C2, then the resistance of R1 would have to be 10 times its reactance, or about 1000 ohms. If the current drawn by the load is 100 milliamperes, then the voltage drop across R1 due to the load current flowing through it will be 1000 ohms times .1 amp (100 ma), or 100 volts. This means that we will be losing 100 volts of our dc voltage across R1. Furthermore, the power being wasted by this resistor will be

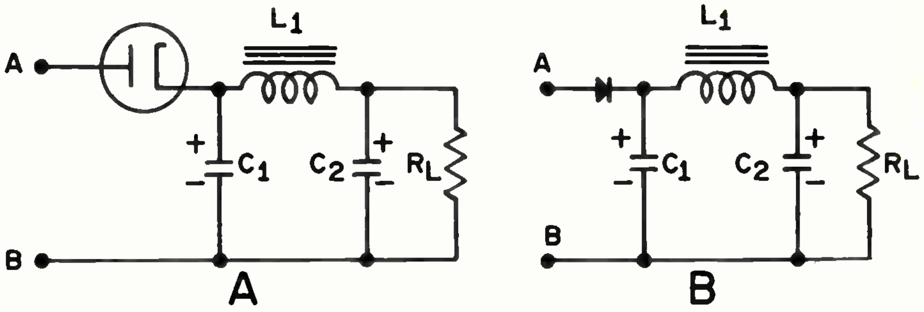

Fig. 15. An L-C filter.

equal to the voltage across it times the current flowing through it, which is 100 × .1, or 10 watts. You can see that we have an appreciable voltage drop and a sizable amount of power wasted by this resistor.

In some cases the current drawn through the filter resistor is not so high that the voltage drop across the resistor cannot be tolerated. Thus you will see this type of filter used in equipment when the current taken from the power supply is moderate. In equipment when the current drawn is high, a different type of filter is used. Such a filter is shown in Fig. 15. Notice that this circuit is identical to Fig. 13, except that we have substituted an iron-core choke for R1. The action of this filter network is quite similar to that of the filter network shown in Fig. 13. Again, capacitor C1 is charged by the rectifier and because there is no resistance in the circuit other than the rectifier resistance, it charges to a fairly high value. Just as before, however, the voltage across it will be pulsating (the equivalent of dc with ac superimposed on it).

Now consider the reaction of the choke to ac and dc. You will remember that a choke has inductance, and an inductance offers reactance to the flow of ac through it. At the same time the only opposition that the choke will offer to the flow of dc through it is due to the resistance of the wire used to wind the coil. By using a large size wire, this resistance can be kept quite low. The choke may have a dc resistance of 100 ohms or less and at the same time have a reactance of several thousand ohms to the 60-cycle ac applied to it.

The reaction of the L-C filter to dc is shown in Fig. 16A, and the reaction to ac is shown in Fig. 16B. In 16A we see that as far as the dc is concerned, the choke acts as a

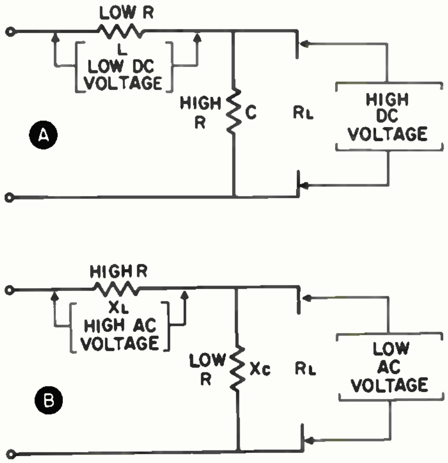

Fig. 16. Equivalent circuit showing the reaction of an L-C filter to dc at A, and to ac at B.

low resistance while the capacitor acts as a very high resistance. Thus, we have practically all of our dc voltage appearing across the capacitor and very little of it being lost across the choke. However, as shown in 16B, the choke acts as a high resistance to the ac while the capacitor acts as a low resistance. Thus, most of the ac voltage will appear across the choke and very little of it will appear across the capacitor.

There is another way of looking at the action of the L-C filter. We can consider the charging of the capacitors and the opposition offered by the choke more or less in the same way as we considered the action of the R-C filter in Fig. 13. During the first half-cycle, when terminal A of either rectifier circuit is positive and terminal B is negative, the rectifier will conduct. Electrons will flow from terminal B into the sides of C1 and C2 marked with a minus sign. These electrons will force electrons out of the positive side of C1 and they will flow through the rectifier with little or no opposition. However, the electrons leaving the positive side of C2 will encounter opposition in the choke. This is because at the instant when the electrons first try to get through the choke there is no magnetic field built up in the choke. You will remember that a choke is a device that opposes any change in current flowing through it. Therefore, the choke tries to keep the electrons leaving the positive side of C2 from flowing through it. Eventually this opposition offered by the choke is overcome, a magnetic field is built up in the choke, and some of the electrons can flow through the choke and capacitor C2 will be charged. However, the voltage to which C2 is charged will not be as high as the voltage to which C1 is charged because of the opposition of the choke.

When the ac input voltage drops below the voltage to which C1 is charged, the rectifier will no longer conduct and no current can flow through it. Now C1 and C2 and choke L1 must supply the current needed by the load. C2 does this by attempting to discharge. C1 also tries to discharge to charge C2 and to supply part of the current required by the load. At the same time there is a magnetic field built up in the choke L1 which does not collapse instantly but instead tries to keep current flowing in the direction it was flowing when the rectifier was conducting. It too helps to maintain the current flow through the load RL. Thus in this type of filter we have energy stored in three places: the capacitors C1 and C2 (as we did in the circuit in Fig. 13), and in the magnetic field of choke L1.

In the circuits shown in Fig. 15, the rectifier tube in Fig. 15A offers a certain amount of resistance to the flow of current through it. In addition, the rectifier tube has a cathode which must be heated by a heater. It takes some time for the cathode to come up to operating temperature; when a tube first starts conducting, the cathode is below normal operating temperature, and the tube offers a higher resistance to the flow of current through it than it does when the tube reaches its full operating temperature. Thus when the power supply is first turned on and the tube reaches a temperature at which the cathode begins to emit electrons, the tube offers considerable resistance to the flow of current through it. This limits the charging current through the tube that charges the input filter capacitor C1. In a matter of a few seconds capacitor C1 is charged and from then on the current that must flow through the tube is within the tube's capabilities.

In the circuit shown in Fig. 15B, however, the silicon rectifier does not have a cathode which must be heated -- as soon as the power is turned on the rectifier begins to conduct to charge the input capacitor C1. If you turn the equipment on at the peak of the ac cycle there will be a very high voltage immediately impressed across C1 and a very high current will flow through the rectifier. As a matter of fact, the current might be so high that it could burn out the rectifier. Even if the power is turned on when the ac voltage is at zero, a high current will flow through the diode to charge C1 as the voltage rises to a peak value with terminal A positive with respect to terminal B. If C1 is large enough, this could burn out the rectifier.

This problem of excessively high charging current can be overcome with the circuit shown in Fig. 17. Here a resistor is connected in series with the silicon rectifier to limit the current flow. In some equipment, this resistor is a fairly low resistance, fixed-value resistor. In other applications, the resistor may be a thermistor. You will remember that a thermistor is a resistor with a negative temperature coefficient. This means that the resistance of the thermistor decreases as its temperature increases.

With a thermistor for the resistor R1 shown in the circuit in Fig. 17, the thermistor will offer a fairly high resistance to current flow when the equipment is first turned on. This will limit the charging current that flows through the diode to charge C1 to a reasonable value. As the current flowing to the thermistor heats the thermistor and its resistance goes down, the charge across capacitor C1 will build up slowly so that the diode current never reaches an excessively high value. By the time the capacitor is fully charged, the thermistor temperature will have increased to a point where the resistance of the thermistor has dropped to a low value so that the thermistor has very little effect on the overall operation of the circuit.

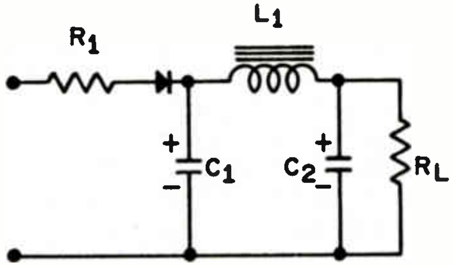

Fig. 17. Power supply with series-limiting resistor.

If you have to service a power supply of this type (where a resistor or a thermistor is used in the circuit in series with a silicon rectifier) and you find that the resistor or thermistor is opened, do not simply short the resistor or thermistor out of the circuit. If you do the chances are that the diode will burn out either the first time that you turn the equipment on or shortly thereafter.

The rectifier tubes used in low power equipment such as radio and television receivers are high vacuum rectifier tubes. However, in transmitters and in industrial applications where high voltages are involved you will often run into mercury-vapor rectifier tubes. Tubes of this type cannot be subjected to high peak currents through them without damaging the tube. A mercury-vapor rectifier tube in the circuit such as shown in Fig. 15A lasts only a short time. We can keep the peak current through the tube down to a safe value by using a somewhat different filter circuit known as a choke-input filter.

CHOKE-INPUT FILTERS

The filter circuits shown in Figs. 15 and 17 are called capacitor-input filters because the rectifier is connected directly to the input filter capacitor. A choke-input filter such as those frequently used with a mercury-vapor rectifier tube is shown in Fig. 18. Here, the rectifier tube is connected to a filter choke rather than a capacitor. Power supplies of this type will be found in radio and television transmitters and in industrial applications where comparatively high voltages are encountered.

It is easy to see how this type of filter works when we remember that the pulsating dc at the output of the rectifier tube is actually dc with ac superimposed on it. The choke offers little or no opposition to the flow of dc through it. On the other hand, the choke offers a high reactance to the flow of ac through it and at the same time the capacitor offers a low reactance to the ac across it. Thus the choke and the capacitor form a voltage divider network for the ac, so that most of the ac is dropped across the filter choke and very little of it appears across the load.

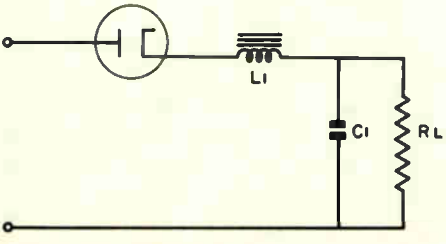

Fig. 18. A choke-input filter.

A more elaborate filter network is the two-section filter shown in Fig. 19. Again, it is a choke-input filter because the first element in the filter network is a choke. This type of filter network is frequently used in power supplies of radio and TV transmitters and of industrial electronic equipment where mercury-vapor rectifier tubes are used.

The choke-input filter has several advantages over the capacitor-input filter, even though the voltage obtained at the output of a choke-input filter is not quite as high as it is at the output of equivalent capacitor-input filters. In other words, if you feed the same pulsating dc into a choke-input filter you will not obtain as high an output voltage for a given load as you can with a capacitor-input filter. However, this type of filter has better voltage regulation than a capacitor-input filter. The voltage regulation of a power supply is the ratio of the full-load voltage to the no-load voltage. With a choke-input filter there is not as great a variation between the no-load and the full-load voltages as there is in the capacitor-input filter.

Another big advantage of the choke-input filter is that the peak current passed by the rectifier tube is held to a reasonable value. In a choke-input filter, the choke offers considerable reactance to any change in current flow through it. Thus, when the rectifier tube tries to conduct current heavily to charge C1 in Fig. 19, the input-filter choke L1 offers considerable reactance or opposition to the change in current flow through it. It tends to smooth

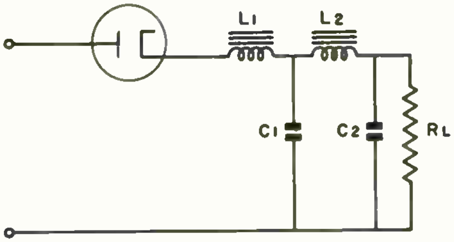

Fig. 19. A two-section choke-input filter.

out the pulses of current through the rectifier tube. The current pulse flowing through the rectifier tube flows for a slightly longer time than it would flow with an equivalent capacitor-input type of filter, and the peak amplitude of the current flowing through the rectifier tube is not as high as it would be with the capacitor input filter. This is a big advantage in a power supply using mercury-vapor rectifier tubes, because they can easily be destroyed by excessively high current pulses through them.

The filter network shown in Fig. 19 is quite effective in eliminating hum. Consider what would happen if the output of the rectifier had an ac voltage of 100 volts superimposed on the dc. If the two sections of the filter network are designed so that each choke has a reactance about 10 times as high as the reactance of the capacitors, each section will have approximately a 10-to-1 ripple voltage division; thus if there are 100 volts ac at the output of the rectifier, L1 and C1 will divide this voltage so that there will be only 10 volts appearing across C1. Now L2 and C2 act as a voltage divider network and divide this 10 volts further, so that the voltage across C2 would be only 1 volt. Thus, the two-section filter has reduced the ac hum or ripple voltage at the rectifier output from 100 volts to 1 volt.

The input filter choke, which is L1 in Fig. 19, is often a swinging choke. A swinging choke is designed so that it saturates rather easily and thus its inductance will vary appreciably as the current through the choke changes. When the current through the choke becomes high, the inductance and hence the inductive reactance of the choke decrease, but when the current through the choke is low, the inductance and hence the inductive reactance increase. Thus we have in effect a variable reactance between the rectifier tube and the input-filter capacitor; this variable reactance helps to improve voltage regulation at the power supply output. This type of choke is particularly useful in circuits where the load current goes through wide variations. If the load current goes down, the reactance of the choke increases. The increased reactance limits the charging action of the rectifier tube and keeps the output voltage from rising appreciably. On the other hand, if the load current increases, the reactance of the choke decreases, allowing the rectifier to charge C1 to a higher value so the capacitor can supply the increased current demand.

FACTORS AFFECTING THE OUTPUT VOLTAGE

In any filter network containing a filter choke or a filter resistor, the dc current flowing through the load must also flow through the filter choke or filter resistor. Thus, there will be a voltage drop across this choke or resistor; the exact value of the voltage drop will depend upon the dc resistance and the current flowing. We already pointed out that if a 1000-ohm filter resistor is used in the circuit and the current that is flowing is 100 milliamperes, the voltage drop across the filter resistor will be 100 volts. On the other hand, if a filter choke having a dc resistance of 100 ohms is used, a current of 100 milliamperes will produce a voltage drop of only 10 volts across it.

If the current drawn by the load changes, the output voltage at the output of the filter network will change. You can see why this is so-- the current must flow through the filter resistor or filter choke. If the current flowing through the choke or resistor changes, the voltage drop across it will change, and hence the voltage at the output of the power supply will have some tendency to change.

The output voltage is also affected by the size of the filter capacitors used. If the filter capacitors used are small, then the rectifier is unable to keep them completely charged; if the filter capacitors are large, once the rectifier gets them charged, they will stay charged to a voltage near the peak ac voltage being applied to the rectifier tube.

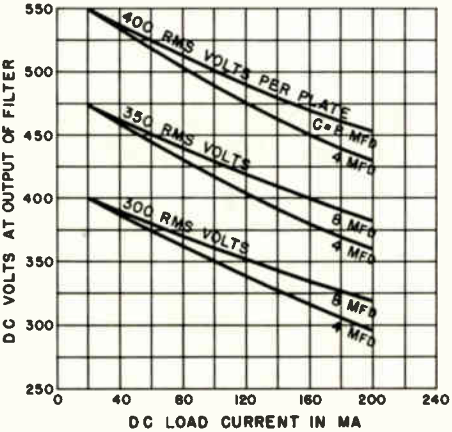

Fig. 20. How the size of the input capacitor of a filter affects the output voltage for different values of load current.

Of course, it is difficult to say whether a filter capacitor is large or small. Whether or not it is large for the particular circuit depends upon how much current is being drawn from the circuit. If the current drain is low, then a capacitor of 10 or 20-mfd will usually be sufficient to keep the power supply output voltage at or near the peak value of the ac voltage applied to the rectifier tube. However, if the current drain from the power supply is large, then the voltage across the power supply output will be considerably less than the peak ac value if the capacitors used are 10-mfd or 20-mfd capacitors.

To give you some idea of how the size of the input filter capacitor affects the output voltage, we have shown a graph in Fig. 20. The graph is for a full-wave rectifier. It shows how the output voltage varies with different load currents for both 4-mfd and 8-mfd capacitors. We have shown this for three separate input voltages. Notice that in each case when the current drain is low, the output voltage is substantially above the rms input voltage applied to the rectifier. Remember, of course, that the peak value of a 300-volt rms voltage is actually 1.4 times 300 volts.

Fig. 21 shows a comparison between a choke-input and capacitor-input type of filter. Notice that with a capacitor input the output voltage at low loads is substantially higher than it is for a choke input. However, as the load is increased, the output voltage from a capacitor-input type of filter drops rapidly. The output voltage from the choke-input type filter also drops as the load is increased, but it does not drop nearly as rapidly as it does with a capacitor-input type of filter.

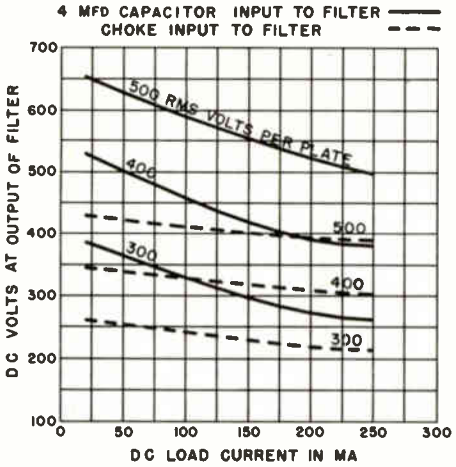

Fig. 21. How the output voltage of a filter network varies for different values of load currents and input voltages. The solid curves are for a capacitor-input filter; the dashed curves for a choke-input filter.

SUMMARY

In this section we have covered some of the more important types of filter networks you are likely to encounter in your career as an electronics technician. You have seen that these networks vary from comparatively simple filters consisting only of a capacitor up to networks containing two chokes and two filter capacitors.

Simpler types of filter networks can be used where the current drain is low and where the filtering does not have to be very good. The more elaborate filters are used in power supplies having a high current drain and in cases where good filtering is required to supply pure dc at the power supply output.

The circuits in this section of the lesson are shown with a half-wave rectifier. The same filter circuits are also used with full-wave rectifiers.

Study the circuits shown in this section. You should be familiar with each of these circuits. You might try drawing these circuits several times to get familiar with the circuit arrangement. Copy them from the book the first few times you try drawing them and then try to reproduce the circuit from memory. This will help you remember what the circuits look like, and if you can remember what they look like, the chances are that you'll be able to remember how they work.

SELF-TEST QUESTIONS

(i) To what value may the input filter capacitor charge in a simple capacitor filter such as shown in Fig. 11?

(j) In what type of application may a simple capacitor-type filter (such as shown in Fig. 11) be used?

(k) What advantage does an R-C pi-type filter (such as shown in Fig. 13) have over the simple capacitor-type filter shown in Fig. 11?

(l) What is the disadvantage of the R-C pi-type filter, and how can this disadvantage be overcome?

(m) What is the purpose of the resistor R1 in the power supply shown in Fig. 17?

(n) Why are choke-input filters used with mercury-vapor rectifier tubes?

(o) What advantage does a choke-input filter have over a capacitor-input filter?

(p) What is a swinging choke?

Typical Power Supplies

The two main sections of the power supply are the rectifier and the filter section. Now that we have discussed both these sections, let's examine some typical power supplies and see what they look like. First we'll look at some power supplies using tube-type rectifiers which might be found in equipment using vacuum tubes. Remember that in these circuits the rectifier operates in the same way as a selenium or silicon rectifier would operate. Insofar as the rectification action is concerned, it makes little difference whether a tube, a selenium rectifier, or a silicon rectifier is used. In the circuits where tubes are used, we will in some cases show how the tube heaters are connected. After looking at a few tube circuits we will look at some typical power supplies using silicon rectifiers and then at a more complex regulated supply.

UNIVERSAL AC-DC POWER SUPPLIES

The universal ac-dc power supply is so called because it can be operated from either an ac or a dc power line. When these power supplies were first used in radio receivers, manufacturers played this feature up, but actually this type of power supply is used to keep costs at a minimum.

The circuit of an ac-dc power supply for a 5-tube radio receiver is shown in Fig. 22. This supply not only supplies the dc voltages required by the plates and screens of the tubes in the receiver but also contains the heater supply for the heaters of the various tubes. First, let us look at the heater supply. Notice that the heaters of the various tubes are connected in series and that they are operated on ac. In this type of power supply you will always find that the heater of the rectifier tube, in this case a 35W4 tube, is connected directly to one side of the power line. The heater of this particular tube is tapped, and a pilot light is connected in parallel with one part of the heater. The pilot light will light when the set is turned on. The tube is designed to be operated with the pilot light connected in parallel with part of the heater, so if in servicing a receiver using a tube with a pilot light tap you should find that the pilot light is burned out, it is a good idea to replace it to keep the heater current in the rectifier tube within its rated value.

Next to the 35W4 rectifier tube in the heater circuit (or heater string, as it is usually called) you will always find the high-voltage power output tube. By a high-voltage tube we mean a tube that requires a high heater voltage. In the diagram we have shown, the tube is a 50B5 tube. As the 50 suggests, a heater voltage of 50 volts is required to operate the tube.

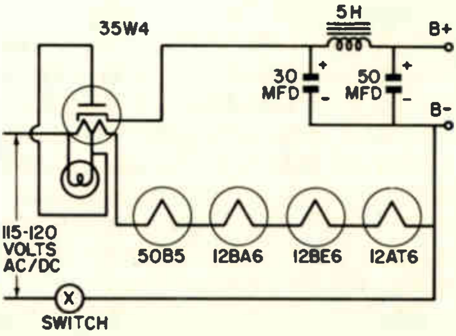

Fig. 22. A typical ac-dc power supply.

Next to the output tube you will usually find the i-f tube. In this diagram, the i-f tube is a 12BA6 tube. It is a tube with a 12.6-volt heater.

Next to the i-f tube you will find the converter tube. The 12BE6 tube is a converter tube designed so that the single tube performs two tasks: one part of the tube is the oscillator and the other part is the mixer.

The last tube in the heater string is always the first audio tube. In this circuit it is a 12AT6 tube. This tube is placed at the end of the heater string nearest B- to keep hum at a minimum, because hum picked up in the first audio tube will be amplified by the entire audio system and could be objectionable. The 12AT6 tube is a dual-diode-triode tube: it has two diodes and a triode inside the same glass envelope. As the 12 preceding the type designation suggests, the tube requires a heater voltage of about 12 volts--to be exact, 12.6 volts.

Now if we examine the rectifier circuit you will see that the plate is connected to a center tap on the rectifier heater. This means that the B supply current flowing through the plate of the tube must flow either through part of the rectifier heater or through the pilot light back to one side of the power line. The purpose of connecting the plate this way is to provide some protection in the event of a short in the receiver. If there is a short in the receiver, the rectifier tube will begin passing excessive current. If this current becomes too high, the pilot light and half the rectifier heater will burn out, opening the circuit and protecting the receiver and the house wiring.

The rest of the power supply is similar to the circuit you studied already. The filter network consists of a capacitor-input filter; the input filter capacitor is the 30-mfd capacitor, and the output filter capacitor is the 50-mfd capacitor. Usually these two capacitors are in a single container that has only three leads brought out from it. Since the negative leads are both connected to B-, a common negative lead and two separate positive leads are usually used. The capacitor is usually a tubular type of capacitor with a paper cover impregnated with wax. The capacitor is mounted on the receiver chassis by means of a mounting strap, or in a receiver with a printed circuit board, the leads are soldered directly to the circuit board. Often this is the only kind of mechanical mounting used.

Capacitors in this type of receiver are usually rated at 150 volts. The normal output voltage of this type of power supply under load is usually somewhere between 90 and 105 volts.

Not all universal ac-dc power supplies use a filter choke. In the circuit shown in Fig. 22, the plates and screens of all of the tubes are operated from the B+ output of this power supply. However, sometimes you will find a filter resistor used in the power supply in place of the filter choke. When this is done, the plate of the output tube is usually connected directly to the cathode of the rectifier tube so that the current drawn by the output tube plate will not flow through the filter resistor. This tube usually draws more current than all the other tubes in the receiver combined.

The output tube is normally a beam tube or a pentode tube, and the plate current depends very little on plate voltage. Therefore if there is some hum voltage applied to the plate of the tube, it usually does not cause any plate current variation and hence is not heard as hum in the output from the loudspeaker. The screen voltage for the output tube and the plate and screen voltages for the remaining tubes are obtained at the output of the power supply where the additional filtering obtained from the filter resistor and the output filter capacitor will reduce the ripple from the rectifier to a low value.

In some of the later table-model radio receivers only four tubes are used; a selenium rectifier or a silicon rectifier is used in place of a rectifier tube because either of these has a considerably longer life. In receivers of this type, tubes with higher heater voltage requirements are often used, so that the sum of the heater voltages required by the four tubes adds up to about 120 volts. If the heater voltage required by the tubes is less than the line voltage, a voltage-dropping resistor can be placed in series with the heaters to use up the leftover voltage. This will cause the total voltage drop across the series-dropping resistor and the tubes to be equal to the line voltage, thus allowing each of the tubes to have its required heater voltage.

Of course, in any heater string where tube heaters are connected in series, all the tubes must have the same heater current rating. Tubes designed for this type of service have what is called a controlled warm-up. This means that the tube heaters are made so that they all reach operating temperature at the same time. This prevents one tube from warming up too quickly and from having too high a voltage across its heater.

The voltage across the tube heater will depend upon its resistance, which changes with temperature. As long as all the tubes warm up at the same rate, their resistances change at the same rate. In this way, a high voltage across any of the tubes is avoided.

Before leaving our study of this type of power supply, it is worthwhile to consider what will happen if a tube such as the 12BA6 tube in Fig. 22 develops a cathode-to-heater shortage. The cathode will usually be connected either to B- directly or to B- through a low-value resistor; this will effectively short out the heaters of the 12BE6 and 12AT6 tubes and, as a result, these tubes will not light.

If you're called upon to service a receiver of this type and you find that one or more of the tubes is not heating, look for a cathode-to-heater short in either the tube which doesn't light that is highest up on the string, or the tube preceding it. If none of the tubes lights this is an indication, since the tubes are connected in series, that the series string is open -- chances are that the heater of one of the tubes has burned out.

A TYPICAL FULL-WAVE POWER SUPPLY

Fig. 23 illustrates a typical power supply using a power transformer and full-wave rectifier. This type is found in many radio and TV receivers and transmitting equipment, as well as in the equipment used in industrial electronics.

Notice that the power transformer has a primary winding to which the 115-volt ac power line is connected; a high-voltage secondary with its center tap grounded, and the two end leads connected to the plates of the rectifier tube; and the two filament

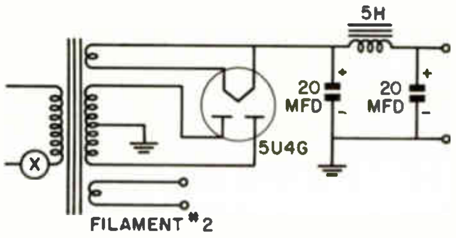

Fig. 23. A typical power supply using a transformer and full-wave rectifier.

windings. One filament winding is used to supply the heater voltage required by the rectifier tube, and one filament winding is used to supply the heater voltage for all the other tubes in the set.

In this power supply we have shown a 5U4G rectifier tube, which requires a heater voltage of 5 volts and a heater current of 3 amps. Thus the rectifier filament winding on the transformer must be capable of supplying 5 volts at a current of 3 amperes.

The winding marked filament number two is used to supply the heater voltage required by all the other tubes in the set. You will notice that this winding is called the filament winding, not the heater winding. This is a carry-over from the old days of radio when most of the tubes were filament-type tubes and few had a separate cathode and heater.

In an electronic device using this type of power supply, the heaters of the tubes (with the exception of the rectifier tube) are connected in parallel. Since the tubes are connected in parallel, you will find that all of the tubes are designed to operate from the same heater voltage. In most cases equipment using this type of power supply has tubes with heater voltage ratings of 6.3 volts. The filament winding must be capable of supplying the heater current required by all of the tubes. The tubes may require different heater currents since they are connected in parallel. You can determine the total current the winding must supply by looking up the heater current required by the individual tubes in a tube manual and adding these figures together.

Again, the filter network used in this power supply is a capacitor-input type. Notice that the capacitors have a lower capacity than those used in the circuit shown in Fig. 22. It is not as necessary to use large capacitors in a full-wave rectifier type of power supply as it is in a half-wave rectifier to obtain the same amount of filtering. Of course, in some power supplies in which it is essential to keep the hum voltage very low, you will find larger filter capacitors. You may also find a two-section filter using an additional choke and a third filter capacitor.

In a power supply such as the one shown in Fig. 23, the two capacitors will probably be mounted in a single container. If a cardboard tubular type is used, one common negative lead and two separate positive leads will be brought out of the container. The same color leads will probably be used for the two positive sections since they both have the same capacity. In some pieces of equipment a metal can-type capacitor might be used -- with this type the can is usually the negative terminal. Mounting the capacitor on the metal chassis automatically makes the connection between the negative terminal and the chassis. The positive leads are brought out of two separate terminals.

DUAL-VOLTAGE POWER SUPPLIES

A diagram of a typical dual-voltage power supply is shown in Fig. 24. This diagram is actually quite similar to the diagram of circuits used in a modern color-TV receiver. Notice that a voltage that is negative with respect to ground is developed by the diode D1 and its associated circuitry. Diodes D2 and D3 are used in a half-wave voltage doubler circuit.

In this circuit when terminal A is negative with respect to terminal B, current flows from A through R1 and D1 to charge capacitor C1. A simple pi-type R-C filter is used in this section of the power supply because the current requirements are low and there will be very little voltage drop across R2. At the same time with the two capacitors, small value capacitors can be used and adequate filtering obtained.

When terminal A is negative, current also flows through the thermistor R3 through R4 and into the negative plate of capacitor C3. Electrons flow out of the positive plate through the diode D2 back to terminal B of the power line. When terminal A of the power line is positive and terminal B is negative the voltage will be placed in series with the voltage built up across C3, so that capacitor C4 is charged to a value approaching twice the peak line voltage through diode D3. This provides an output voltage which is positive with respect to ground and approximately equal to twice the ac line voltage.

The thermistor R3 is put in the circuit to prevent high current surges through the silicon diodes D2 and D3 when the equipment is first turned on. R4 is used in the circuit to provide further protection. If the equipment is turned on and operating for some time, the resistance of the thermistor will drop to a low value. If the equipment is turned off for a

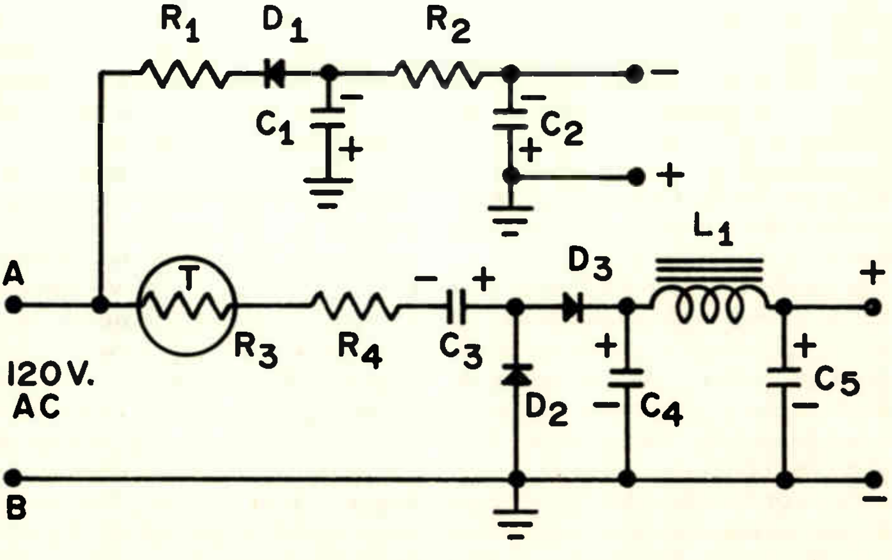

Fig. 24. A typical dual-voltage power supply.

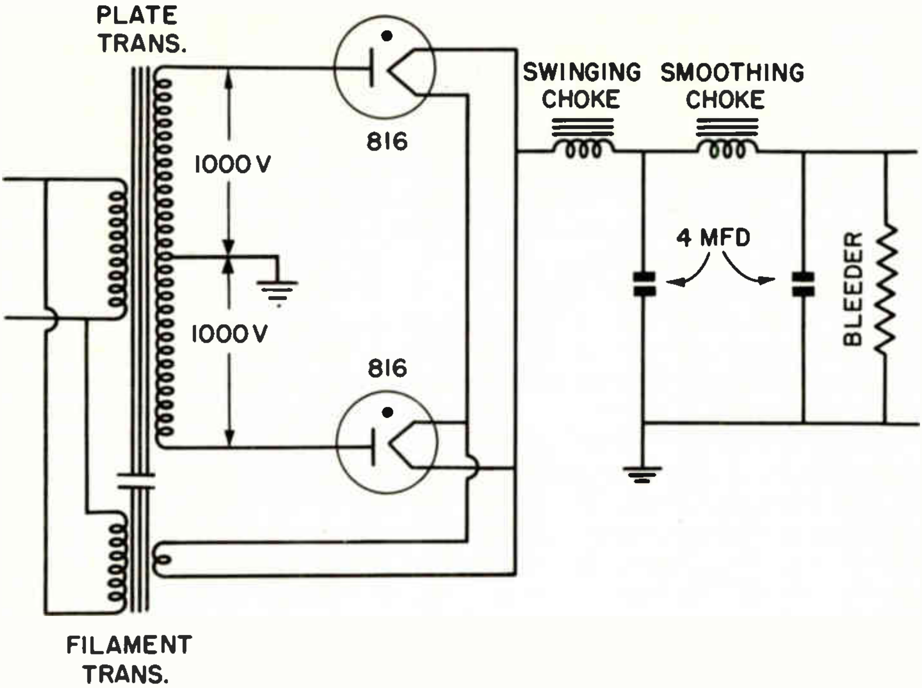

Fig. 25. A typical transmitter power supply.

few seconds and then turned back on, the charging current through the diodes could be quite high and damage them. R4 is put in the circuit; its value does not change and it limits the current through the diodes to prevent their damage under this circumstance.

The power supply shown in Fig. 24 is typical of the power supply you are likely to run into in both monochrome and color television receivers. A voltage-divider network may be used across the output of either supply to provide different value voltages. This power supply is comparatively inexpensive; it eliminates the need of a power transformer and with modern silicon diodes is comparatively trouble-free.

HIGH-VOLTAGE POWER SUPPLIES

Another power supply is shown in Fig. 25. This is the type of power supply you will find in transmitting equipment or in other equipment where high operating voltages are required. Notice that in this power supply, full-wave rectification is used. Also notice that it has two separate rectifier tubes. Separate rectifier tubes rather than a single tube with two plates are used in high-voltage supplies because the voltages are so high that they would simply arc across inside the tube. The type 816 tubes shown in this supply are mercury-vapor tubes designed for use in power supplies where the operating voltages are not too high and where the current requirements are not too great. They are often used in power supplies where the ac input voltage to the rectifier is between 1000 and 2000 volts, and the current drain does not exceed 250 ma. As far as the transmitting-type power supplies are concerned, an output voltage of 1000 volts across each half of the secondary of the high-voltage transformer is not considered high.

The high-voltage transformer found in this type of power supply is frequently called a plate transformer because it is used to supply the high voltage required to operate the plates of the various tubes in the transmitter. The rectifier tubes are operated from a separate filament transformer. In a power supply using type 816 tubes, the filament voltage required by these tubes is 2.5 volts and the current required is 2 amps. Therefore, this filament transformer must be capable of supplying a total of 4 amps at a voltage of 2.5 volts. The filament transformer must have good insulation between the secondary winding, the transformer core, and the primary winding; otherwise the high voltage will arc through the insulation either to the primary winding or to the transformer core.

At the input of the power supply filter network is a swinging choke. This is common practice in transmitter power supplies because it improves the voltage regulation, and also because it affords additional protection for the mercury-vapor rectifier tubes.

The second choke in the power supply is called a smoothing choke. This is the same type of choke shown in the power supplies in Figs. 22 and 23. It is called a smoothing choke in transmitting equipment because its primary purpose is to smooth out the ripple and also to distinguish it from the swinging choke used at the input of the filter network. A smoothing choke is designed to keep its inductance as nearly constant as possible, whereas a swinging choke is designed so that its inductance will vary as the current through it varies.

Notice that the filter capacitors used in this power supply are 4-mfd capacitors. Each of these capacitors is usually mounted in its own separate container. Occasionally you will find two small high-voltage capacitors in the same container, but this is not common practice. Also notice that the capacitors have a much smaller capacity than those in the two power supplies we discussed previously. These capacitors are oil-filled capacitors and it is quite costly to make this type of capacitor with a large capacity. On the other hand, capacitors used in circuits like those in Fig. 22, Fig. 23, and Fig. 24 are electrolytic capacitors and very large capacities can be obtained at a very moderate cost.

Effective filtering is obtained with the smaller-size capacitors in this supply, because two filter chokes are used. The inductance and hence the inductive reactance of these chokes are usually somewhat higher than that of filter chokes used in lower voltage equipment. The choice of using either large chokes or large filter capacitors is simply one of cost. At low voltages it is more economical to use large capacitors and low-inductance chokes, but at high voltages it is more economical to use high-inductance chokes and low capacities. The net result is the same as far as the filtering action is concerned. Another component that you will find in transmitting-type power supplies is a bleeder. A bleeder is a resistor connected across the power supply output. The bleeder serves two purposes: it improves the voltage regulation and is also used for safety.

A bleeder resistor connected across the power supply keeps the minimum current at a reasonable value. If the current drawn by the load connected to this power supply were to drop to zero, the two filter capacitors would be charged up to a value equal to the peak voltage across half of the secondary of the plate transformer. If the transformer had an rms voltage of 1000 volts across each half of the secondary, this would mean that the capacitors would charge up to a voltage of about 1400 volts. This may be high enough to destroy the capacitors. Also, the chokes have a definite maximum voltage that can be applied to them. If the voltage goes too high, the insulation between the choke winding and the core may break down. This will destroy the chokes. If either of the chokes or capacitors shorts, the rectifier tubes will pass such a high current that they may be ruined. There is also the danger of burning out the plate transformer. Furthermore, if the voltage reaches too high a value, the rectifier tubes may arc over internally. A bleeder connected across the power supply output can eliminate this danger. With the bleeder across the output, if the equipment current drops to or almost to zero, the bleeder current will continue to flow. If the output voltage starts to rise, the bleeder current will increase because the current flowing through any resistor increases if the voltage across it increases. The bleeder current will keep the voltage from climbing to an unsafe value.

Another important reason for using the bleeder is that an oil-filled capacitor such as those found in this type of power supply can hold a charge for a long time. If the two 4-mfd capacitors used in the supply were charged up to a voltage of 1000 volts or more and a technician servicing the equipment accidentally touched one of these capacitors, he could receive a very dangerous shock. Under certain conditions it could be fatal. This danger can be greatly reduced by connecting a bleeder across the power supply so that when the equipment is turned off the capacitors are discharged through the bleeder.

You may have occasion to work on high-voltage power supplies at some future date. Remember that a bleeder is connected across the power supply for safety as well as to improve the voltage regulation. Therefore if the bleeder in a power supply burns out, it should be replaced. However, never rely on a bleeder to discharge high-voltage filter capacitors. If you have to work on a high-voltage power supply, your first step should be to remove all voltages from the supply. To do this, turn the power supply off; if there are fuses in it, remove the fuses so that no one can accidentally turn it on; disconnect it completely from the source if you can. Often it is not possible or convenient to completely disconnect the equipment from the voltage source but if it is shut off and any fuse in the circuit is removed, it should be safe. Next, before you start to work on the supply, discharge all filter capacitors in the power supply. The capacitors should be discharged with a heavy metal rod that has a good insulated handle so that you will not come in contact with the metal rod. Use the metal rod to short together the terminals of the capacitor to discharge it. Touch the grounded terminal of the capacitor first and slide the rod over to touch the other terminal. Do this several times to be sure the charge is completely removed. After the capacitors have been discharged, the power supply should be safe to work on.

Keep this point in mind: high voltage capacitors, or for that matter any large capacitors, should be discharged before you start to work on a piece of equipment. Many technicians fail to do this. There are some technicians who can tell about the terrific shock they received when they failed to discharge a filter capacitor. There are others that did not survive the experience to tell about it.

A TRANSISTOR-REGULATED POWER SUPPLY

A regulated power supply employing transistor voltage regulators is shown in Fig. 26. This power supply is used in a TV receiver that is designed for operation from the power line and also from a 12-volt dc source. When the power plug is plugged into a 120-volt line and the switch is turned on, the receiver will operate from the power line. When the power plug is disconnected and switch S1 is closed, the receiver can be operated from a 12-volt battery.

The operation of the power supply from the power line is comparatively simple. Two diodes, D1 and D2, are used in a full-wave rectifier circuit. When the transformer T1, which is a step-down transformer, has a polarity such that the end of the secondary connected to D1 is negative, current will flow through the diode D1 to ground and into the negative plate of C3. Electrons flow out of the positive plate of C3 to the center tap of the power transformer which is positive with respect to the end connected to D1. During the next half-cycle, when the end of the secondary connected to D2 is negative, current will flow through D2 to ground, into the negative plate of C3,

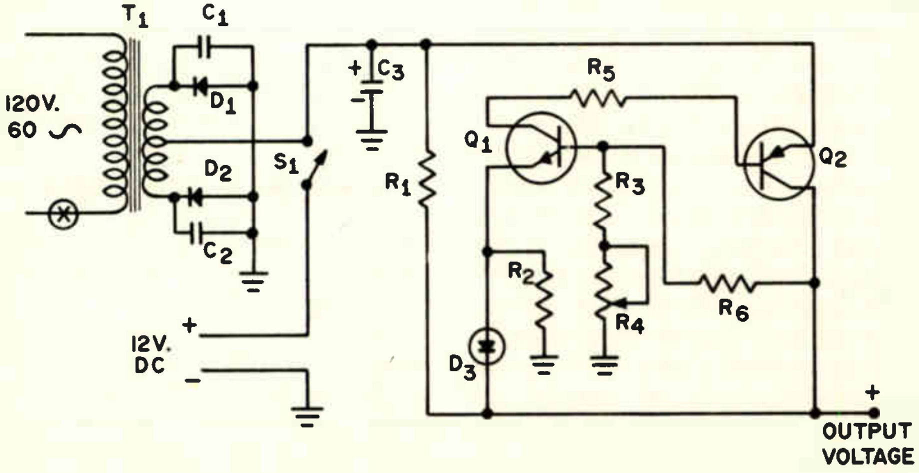

Fig. 26. A transistor-regulated power supply.

out of the positive plate of C3 and back to the center tap of the secondary winding on the power transformer.

The remainder of the components used for the power supply are used for the purpose of regulating the voltage. In other words, the power supply voltage is maintained constant at approximately 12 volts regardless of the load drawn from the supply. The transistor Q2 is a PNP transistor that is used as a series voltage regulator. Notice that the emitter of this transistor connects directly to the positive side of C3. You can consider this transistor as working more or less as a variable resistor: if the output voltage tends to rise, the resistance increases and if the voltage tends to fall, the resistance decreases.

The effective resistance of Q2 is varied by varying the forward bias across the emitter-base junction. Notice the zener diode D3. This diode is connected in series with R2. The zener has a constant voltage of 6.3 volts across it. Therefore, the voltage drop across R2 will be equal to the output voltage minus 6.3 volts. This is the emitter voltage applied to Q1. The base voltage is determined by the voltage division occurring between R4, R3 and R6. R4 is adjustable so that the output voltage can be adjusted to 12 volts. Under these circumstances a certain current will flow through Q1 and through R5 and this will set the forward bias on Q2. If the output voltage tends to rise, the base voltage on Q1 will rise but by an amount less than the emitter voltage. The divider network consisting of R4, R3 and R6 will prevent the base from rising the full amount of the output voltage rise. On the other hand, the voltage across the zener D3 remains constant so that the voltage across R2 will reflect the entire output voltage rise. This will reduce the forward bias on Q1 which, in turn, will reduce the emitter-collector current. The reduction in the emitter-collector current will reduce the voltage drop across R5 which, in turn, will reduce the forward bias on Q2; this has the effect of increasing its resistance. The increased resistance tends to keep the output voltage from increasing.

If the output voltage decreases, the opposite happens. The base voltage on Q1 falls, as does the emitter voltage. However, the emitter voltage falls more than the base voltage, so the forward bias is increased. This increases the emitter-to-collector current through Q1 which increases the forward bias on Q2. This has the effect of reducing the resistance on Q2 and tends to keep the output voltage from falling.

This type of power supply is one of the more complex power supplies that you are likely to encounter in electronic equipment. The voltage regulation is required in order to keep the voltage reasonably constant on the various transistors used on the TV receiver. In most cases, such precise voltage regulation is not required in entertainment-type equipment.

VOLTAGE DIVIDERS

We mentioned previously that more than one operating voltage is sometimes needed in the various stages of a piece of electronic equipment. Rather than use a separate supply for each voltage needed, the usual procedure is to use a single supply designed to give the highest voltage needed, and then obtain the lower voltages required by means of a voltage divider connected across the power supply output. A typical voltage divider is shown in Fig. 27.

In this voltage divider, R1 and R2 are voltage-dropping resistors; they drop the voltage from 300 volts to the required voltages of 200 and 100 volts. R3 is a bleeder used to stabilize the voltages at points B and C. With this type of network, terminal D is the ground or common terminal. Between D and C there is a voltage of 100 volts; terminal C is positive with respect to terminal D. Between D and B there is a voltage of 200 volts and terminal B is positive with respect to terminal D. Finally, between terminals D and A there is the full power supply output voltage of 300 volts, and of course terminal A is positive with respect to terminal D.

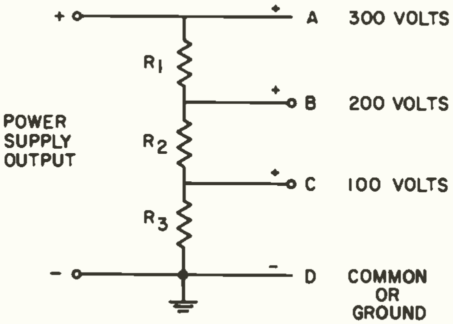

Fig. 27. A voltage-divider network.

The current flowing through R3 is called the bleeder current. It remains fairly constant and is determined primarily by the sizes of R1, R2 and R3. Usually, the size of R3 is chosen so that the bleeder current will be at least as great as the current drawn by the stages connected to terminals C and B. Choosing a value of R3 that will result in a reasonable bleeder current helps maintain good voltage regulation at terminals C and B.

The current flowing through R2 will be made up of the bleeder current plus the current drawn by the stages connected to terminal C. If this current varies, the voltage drop across R2 and hence the voltage at terminal C will vary. However, the bleeder current will remain essentially constant so that if a sizable percentage of the current flowing through R2 is bleeder current, variations in the current drawn by the stages connected to terminal C do not cause too much variation in the voltage drop across R2.

The current flowing through R1 is made up of the bleeder current plus the current drawn by the stages connected to terminals C and B. Again if the bleeder current through R1 represents a sizable part of the total current flow through R1, variations in the current drawn by the stages connected to terminals C and B do not cause too great a variation in the voltage drop across R1 so the voltage at terminal B will remain reasonably constant.

Bleeders are not used in modern midget radio receivers, but you will find them in many of the older sets. They are frequently used in TV receivers, in the low-voltage power supplies in transmitting equipment, and in industrial electronic equipment.

Sometimes one section of a tapped resistor will burn out. Often you can repair the equipment simply by connecting a resistor having the correct resistance and a suitable wattage rating across the defective section. Of course, if separate resistors are used in the voltage divider you can simply replace any defective one. If you do shunt a burned out section of a tapped resistor in a radio receiver and find the equipment is noisy after you have made this repair, the defective section may be making contact intermittently and creating the noise. Of course in this case you must replace the entire unit either with separate resistors connected in series or with a tapped resistor like the original one.

VIBRATOR-TYPE SUPPLIES

The radios installed in automobiles for years used a power supply known as a vibrator type of power supply. A schematic diagram of this type of power supply is shown in Fig. 28. The heart of this type of power supply is the vibrator, which is used to change the dc from the automobile storage battery to a pulsating current in the primary winding of the power transformer.

The vibrator consists of an electromagnet L, and a reed (R-K) placed between two sets of contacts. In the circuit shown in Fig. 28, when the switch is turned to the ON position, current will flow from the negative terminal of the battery through the switch and through the reed towards terminal M. Here it will flow from the reed to contact M, to coil L, through coil L back to the positive side of the battery. The current flowing through the coil creates a magnetic field. This magnetic field attracts the end of the reed K, pulling the reed over toward L and contact N. When the reed makes contact with terminal N, current flows through the upper half of the transformer primary winding. It flows from the top of the winding to the center tap, building up a magnetic field.

At the same instant that the reed is making its contact with terminal N, it will break its contact with terminal M so that the electromagnet will no longer be energized and the field about it will collapse. The reed is made of a spring type material so that it springs back until it makes contact with both terminal M and terminal O. At the instant contact is made with terminal O, current flows through the lower half of the primary winding of the transformer, flowing from the bottom of the winding towards the center tap. The current is flowing through the primary winding in the opposite direction to the direction in which it was flowing through the upper half of the trans-

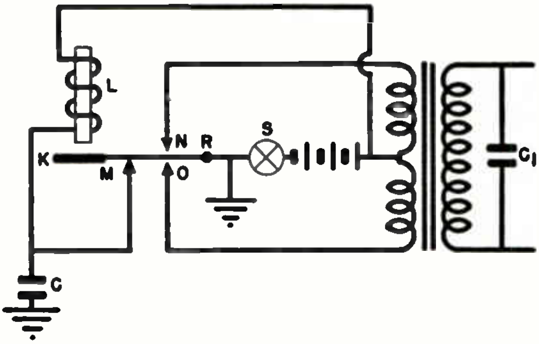

Fig. 28. A vibrator circuit.

former winding. Thus we have a field built up in one direction and then in the opposite direction. At the same time the fact that the reed makes contact with terminal M will once again complete the circuit through the electromagnet so the reed will swing over to the magnet again, making contact with terminal N. As you can see this action causes the reed to vibrate back and forth between terminals N and O. Thus we have a field built up in the primary first in one direction and then in the opposite direction. Building up this field, collapsing it, and then building up a reverse field and collapsing it, means that we have a continually changing magnetic field cutting the secondary of the transformer. By putting a large enough number of turns on the secondary, we can obtain whatever voltage we may require for the operation of the receiver.

A complete vibrator-type power supply is shown in Fig. 29. Notice that the secondary of the vibrator transformer is center tapped and that a full-wave rectifier is used. The capacitor C_2 is called a buffer capacitor. This is a high voltage paper capacitor that is used to keep sharp noise pulses out of the power supply. The size is usually quite critical and if it is necessary to replace the buffer capacitor in a receiver using this type of power supply, you should use a capacitor having the same capacity as the original.

In a vibrator-type power supply there is considerable sparking as the reed vibrates back and forth. This sets up a radio-frequency type of interference which could get through the rectifier and cause considerable interference in the receiver. In the power supply shown in Fig. 29, the choke L and the capacitor C are called hash suppressors. This rf interference or noise is called hash; the choke and the capacitor are put in the power supply in order to keep as much as possible of this hash or noise out of the power supply output. Capacitor C acts like a short circuit to these radio frequency pulses, and choke L acts like a very high impedance to them. Thus L and C form a voltage-divider network, with most of the voltage appearing across the high impedance L and little or no voltage across the low impedance C.

Vibrator-type power supplies were used in almost all automobile receivers in automobiles using 6-volt ignition systems. However, in newer cars, a 12-volt ignition system is used. The first receivers made for these cars also used vibrator type supplies, but tube manufacturers designed special tubes that will operate with plate and screen voltages as low as 12 volts. These 12-volt tubes were used in automobile receivers for a few years, but they too were replaced by transistors. Since transistors operate from low voltages, the vibrator type of power supply is no longer needed. These supplies were not only costly, but in addition they were one of the most troublesome sections of the automobile receiver.

SUMMARY

The power supplies we have shown in this section of this lesson are typical of the various types of power supplies you are likely to encounter as an electronics technician. You will find many variations of these circuits, but these are the basic circuits. Spend some time studying

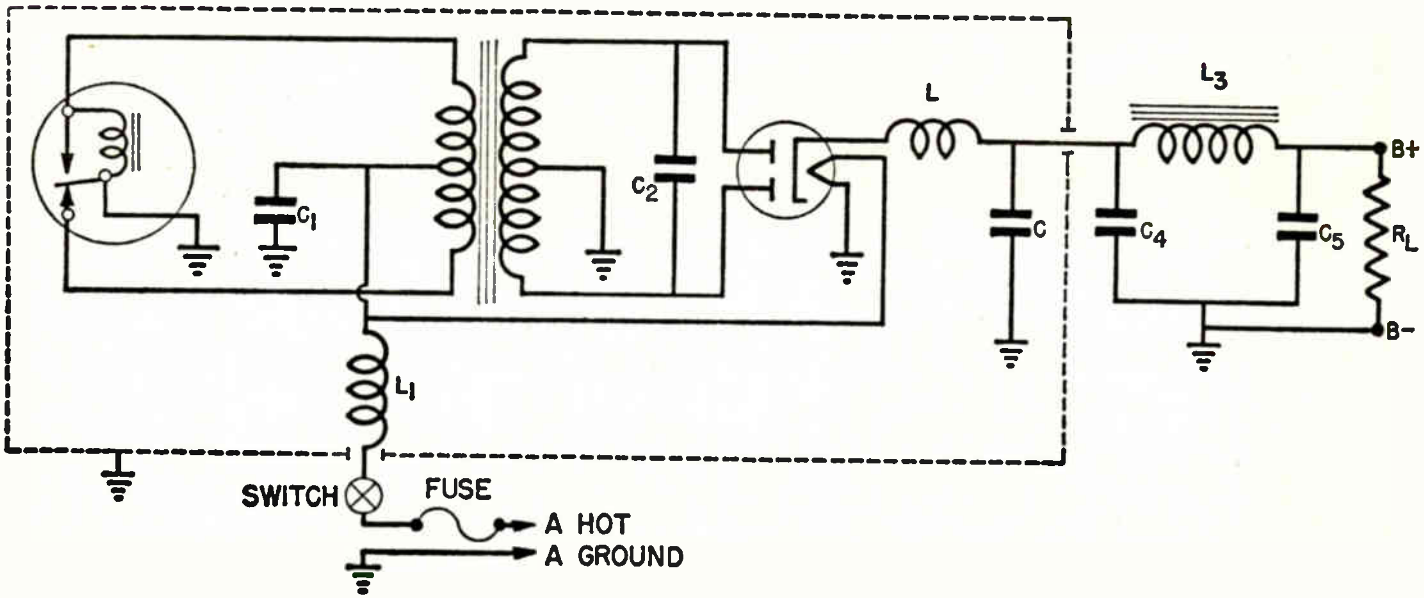

Fig. 29. A complete vibrator power supply.

these circuits so you will know what they look like.

In servicing these power supplies, keep in mind that the values of the various components used are generally not extremely critical. Manufacturers usually use as small a filter capacitor as they can in a circuit. It is more economical to use a small capacitor than to use a large one. Therefore, if you have an ac-dc receiver that uses a 20-40 mfd, 150-volt capacitor and you find it necessary to replace the filter capacitor, there is no reason why you could not use a 30-50 mfd, 150-volt capacitor in its place. Some variation of part values can be made without affecting the performance of the equipment.

It is also possible to use capacitors having a higher voltage rating than those used originally. This will simply provide an additional margin of safety. You may find that you cannot do this in large transmitter power supplies because there isn't room to mount a capacitor with a higher voltage rating, but usually in radio, TV, and most small pieces of industrial electronic equipment there is enough room to put in a capacitor of slightly larger physical size than the original.

SELF-TEST QUESTIONS

(q) Draw a schematic diagram of a typical ac-dc power supply found in a five-tube radio.

(r) In the circuit shown in Fig. 22, why is the 12AT6 tube placed at the B- end of the string?

(s) If in an ac-dc receiver in which the heaters of the tubes are connected in series and none of the tubes lights what would you suspect the cause of the trouble to be?

(t) Why are the filter capacitors used in the power supply shown in Fig. 23 smaller in capacity than the filter capacitors used in the power supply shown in Fig. 22?

(u) What is the purpose of R3 in Fig. 24?

(v) What is the purpose of R4 in Fig. 24?

(w) What type of voltage-doubler circuit is used in the power supply shown in Fig. 24?

(x) What purpose does the transistor Q2 serve in the power supply shown in Fig. 26?

(y) What is the purpose of the diode D3 in Fig. 26?

ANSWERS TO SELF-TEST QUESTIONS

(a) There will be 60 current pulses per second through the load.

(b) The disadvantage of the half-wave rectifier circuit is that current flows through the rectifier during one half-cycle and not during the other half-cycle. As a result, the output is somewhat difficult to filter and smooth out to pure dc.

(c) The diode D1 in the circuit shown in Fig. 6 is used to charge the capacitor C1 during one half of each cycle. Capacitor C1 is charged so that during the next half-cycle the voltage across it will be in series with the line voltage. This will place a voltage equal to twice the line voltage across the load and diode D2. Since diode D2 has a very low resistance when it is conducting, the voltage across the load is twice what it would be without the combination of C1 and D1 in the circuit: hence, the circuit is called a voltage-doubler circuit.

(d) The circuit is called a full-wave rectifier circuit because a current pulse flows through the load during each half-cycle. In other words, if the rectifier circuit is operating from a 60-cycle power line there will be 120 current pulses through the load (one for each half-cycle).

(e) The disadvantage of this circuit is that the high voltage winding on the power transformer must be center-tapped. This means that the high-voltage winding on the transformer must have twice the number of turns required to get the desired output voltage across the load. This circuit requires a rather expensive power transformer.

(f) The advantage of the bridge rectifier circuit is that there is a saving in the power transformer cost over that of a transformer that has a tapped high-voltage secondary winding; also, the circuit is capable of good voltage regulation.

(g) The voltage-doubler circuit shown in Fig. 9 is a full-wave voltage doubler. That is, there will be 120 current pulses per second in the output of the voltage doubling capacitor network consisting of C1 and C2. The circuit shown in Fig. 6 is a half-wave voltage-doubler circuit and there will be only 60 current pulses through the load in this circuit. It will be somewhat easier to filter and smooth the output voltage in the circuit shown in Fig. 9 than it will be in the circuit shown in Fig. 6.

(h) A full-wave doubler circuit requires a less expensive power transformer for a given load voltage than the bridge rectifier circuit requires. Also, the voltage-doubler circuit requires only two rectifiers whereas the bridge-rectifier circuit requires four rectifiers. The disadvantage of the full-wave voltage-doubler circuit is that it does not have as good voltage regulation as the bridge-rectifier circuit.

(i) The capacitor in a simple filter circuit such as shown in Fig. 11 may charge up to a value equal to the peak value of the ac input voltage. In the case of a power supply operating from a 120-volt line this is equal to approximately 1.4 times 120 volts.

(j) A simple capacitor-type filter may be used in applications where the current drain is low. With a low current drain the capacitor discharges very little between cycles so that the voltage across the capacitor, and hence the voltage across the load, remains essentially constant.

(k) The R-C pi-type filter is capable of better hum elimination than a simple capacitor-type filter. This type of filter is particularly desirable where the current drain is high enough to discharge the capacitor appreciably between charging cycles in a simple capacitor-type filter.

(l) The disadvantage of the R-C pi-type filter is that there is considerable voltage drop across the filter resistor. This problem can be overcome by using a filter choke such as in the L-C type filter shown in Fig. 15. A filter choke will offer a high opposition to any ac and thus effectively reduce the ac, while at the same time offering a low resistance to the passage of dc through it.

(m) R1 in the power supply shown in Fig. 17 is used to limit the current through the silicon rectifier when the power supply is first turned on. Without this resistance in the circuit, the charging current through the diode to charge C1 may be so high that the rectifier may be destroyed.

(n) To limit the peak current through the tubes. A mercury vapor rectifier tube is easily damaged by a high peak current. The peak current through the rectifier tube is much lower with a choke-input filter than it is with a capacitor-input filter.

(o) A choke-input filter will provide better regulation than a capacitor-input filter. This means that the voltage across the load will vary less with widely varying currents when the filter is a choke-input filter than it will when the filter is a capacitor-input filter.

(p) A swinging choke is a choke whose inductance changes as the current changes. As the current builds up the choke tends to saturate so that its inductance goes down. This tends to reduce the reactance of the choke and hence helps provide better voltage regulation.

(q) See Fig. 22. If you cannot draw this diagram from memory, copy it from the book. Simply drawing the diagram will help you to become familiar with the circuit and remember it in the future.

(r) The 12AT6 tube is the first audio stage. It is placed at the B- end of the heater string in order to keep hum pick-up in the tube as low as possible. Any hum picked up by this tube will be amplified by the entire audio system.

(s) The chances are that the heater of one of the tubes is open.

(t) The power supply shown in Fig. 23 uses a full-wave rectifier. Therefore there will be 120 pulses per second to charge the filter capacitors. The power supply shown in Fig. 22 is a half-wave power supply and there will be only 60 pulses per second to charge the filter capacitor; therefore, larger capacitors are needed to eliminate hum.

(u) R3 in Fig. 24 is a thermistor. A thermistor has a high cold resistance, but the resistance decreases as the thermistor heats up. The thermistor is used in this power supply to protect the diode rectifiers from high current surges when the power supply is first turned on.

(v) R4 is a fixed resistor that is used to protect the diodes in the event the equipment is turned off and then turned back on almost immediately. Under these conditions the resistance of the thermistor will be too low to provide the required protection for the rectifiers and hence R4, along with the hot resistance of the thermistor, limits the current through the diode rectifiers to a safe value.

(w) A half-wave voltage doubler.

(x) Q2 is in series with the B supply voltage. It operates essentially as a variable resistor and is used to regulate the power supply output voltage and keep it at essentially a constant value.

(y) The diode D3 is the zener diode. It provides a reference voltage so that the voltage variations on the emitter of Q1 will be greater than the voltage variations on the base. Thus, changes in output voltage affect the forward bias of the transistor and hence the conduction through it.

Lesson Questions

Be sure to number your Answer Sheet B201.

Place your Student Number on every Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time, or you may run out of lessons before new ones can reach you.

1. What advantage does a silicon rectifier have over a vacuum-tube rectifier?

2. Draw the schematic symbol for a silicon rectifier, and indicate by an arrow the direction in which the current will flow through it.

3. How many pulses per second will you get at the output of a full-wave rectifier that is operated from a 60-cycle power line?

4. What is the purpose of C1 and D1 in the circuit shown in Fig. 6?

5. (a) In the circuit shown in Fig. 6, how many current pulses will there be through the load (60-cycle power line)?
   (b) In the circuit shown in Fig. 9, how many current pulses will there be through the load (60-cycle power line)?

6. In the circuits shown in Fig. 11, what part supplies current to the load when the rectifier is not conducting?

7. Explain the following things in connection with the L-C circuit shown in Fig. 15:
   (a) The action of the choke when ac flows through it.
   (b) The action of the choke when dc flows through it.
   (c) The action of the capacitor when ac flows through it.
   (d) The action of the capacitor when dc flows through it.

8. What type of filter network has better voltage regulation -- the capacitor input or the choke input?

9. If you are servicing a five-tube table model radio that uses a universal ac-dc power supply and you see that two of the tubes are not lighting, where would you look for trouble?

10. How does an increase in output voltage affect Q1 and Q2 in the regulated power supply shown in Fig. 26?

HOW TO START STUDYING

For some people, starting to study is just as hard as getting up in the morning. An alarm clock will work in both cases, so try setting the alarm for a definite study-starting time each day. Start studying promptly and definitely, without sharpening pencils, trimming fingernails or wasting time in other ways.

Beginning is for many people the hardest part of any job they tackle. So formidable does each task appear before starting that they waste the day in dilly-dallying, in day-dreaming, and in wishing they didn't have to do it. The next day and the next after that are the same story. Indecision brings its own delays, making it harder and harder to buckle down to work.

Are you in earnest? Then seize this very minute; begin what you can do or dream you can. Boldness in starting a new lesson is a great moral aid to mastery of that lesson; only begin, and your mind grows alert, eager to keep on working. Begin, and surprisingly soon you will be finished.

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POWER SUPPLIES FOR ELECTRONIC EQUIPMENT

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POWER SUPPLIES
FOR
ELECTRONIC EQUIPMENT

B201

STUDY SCHEDULE NO. 1

☐ **1. Introduction . . . . Pages 1-2**

The basic purpose of a power supply is discussed.

☐ **2. Rectifier Circuits . . . . Pages 3-12**

You learn about half-wave, full-wave, and bridge-type rectifier circuits using both vacuum-tube and selenium rectifiers.

☐ **3. Filter Circuits . . . . Pages 13-25**

In this section we take up capacitor filters, R-C filters, L-C filters, and choke input filters, and learn what factors affect the output voltage of a filter network.

☐ **4. Typical Power Supplies . . . . Pages 26-37**

You study ac-dc supplies, full-wave power supplies, and high-voltage supplies.

☐ **5. Answer Lesson Questions.**

☐ **6. Start Studying the Next Lesson.**

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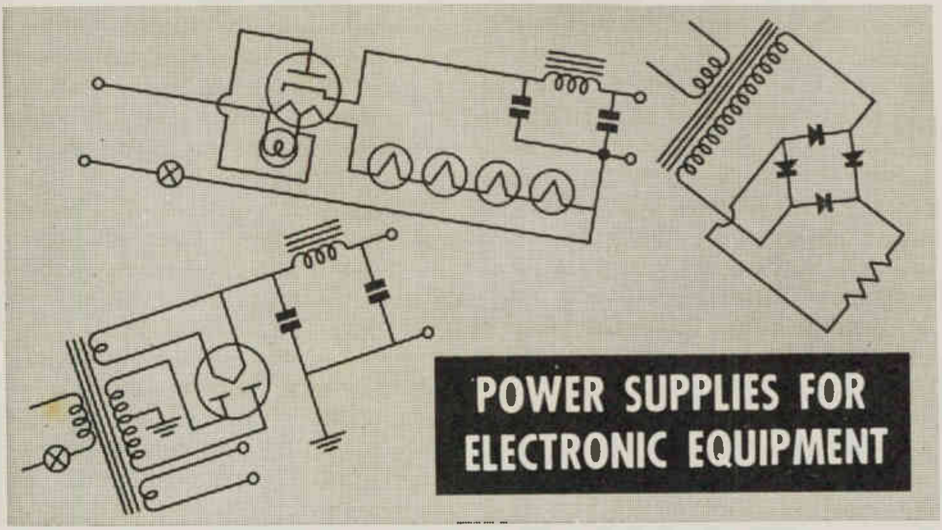

POWER SUPPLIES FOR ELECTRONIC EQUIPMENT

One of the most important sections in electronic equipment is the power supply. It is the section that furnishes the operating voltages and currents required by the various stages. If the power supply is not operating properly, the equipment can't do the job it's supposed to do.

In your career as an electronics technician, you will encounter many different types of power supplies. In equipment using tubes you will find power supplies that must supply the heater voltage for the various tubes and, in addition, a dc supply voltage that is often considerably higher than the power line voltage.

On the other hand, the power supply in transistorized equipment will be quite different from that used in tube-operated equipment. Most power supplies in transistorized equipment will have to reduce the voltage to some value less than the line voltage.

However, the current requirements of the power supply in a transistorized piece of equipment may be considerably higher than those of a power supply in a similar tube-operated device. All power supplies have basically the same function, regardless of the parts and circuitry used to make them; the power supply must supply the operating voltages and currents required by the various stages in the equipment.

You have already studied the basic components used in power supplies. In this lesson you will learn more about these components and how they are used together in this particular application. You will be introduced to some new circuits and will learn enough about power supplies to enable you to understand the purpose for which each part in a power supply is used. Once you know why the various parts are used and understand what each one is supposed to do, you should be able to service any power supply defect you encounter.

We will first take up the different rectifier circuits used in modern power supplies. The power supplied by power companies for home and industrial use is ac power, whereas the tubes and transistors used in electronic equipment require dc operating voltages. Therefore, in a power supply designed to operate from a power line, we must have some means of changing the ac to dc. The device used to do this is called a rectifier.

Once the ac is changed to dc by a rectifier, we have what is called a pulsating dc at the output of the rectifier. This is actually dc with ac superimposed on it. A power supply must therefore have some means of filtering or smoothing the pulsating dc to get pure dc. This is done by means of a filter network, which separates the ac and dc components of the pulsating dc at the rectifier output so that only the dc appears at the output of the filter network.

Many power supplies also have some type of voltage-divider network. Such a network is designed to provide several different operating voltages from one power supply. All the tubes or transistors in a piece of electronic equipment may not require the same operating voltage. It is more economical to use a single power supply and a voltage divider than to use a separate power supply for each voltage needed.

The power supplies in modern electronic equipment use solid state rectifiers in most low-voltage applications. Vacuum tubes are seldom used today as rectifiers in such devices as radio or television receivers or in other modern equipment. However, there are still millions of radios and television receivers in use today that do use vacuum-tube rectifiers. Therefore, you will probably have to work on this type of power supply as a service technician even though it is obsolete as far as its use in new equipment is concerned and you still should know how this type of rectifier works. For this reason, we will cover not only the new rectifier circuits using solid state rectifiers, but also a number of the older frequently-used rectifier circuits using vacuum tubes.

Rectifier Circuits

Any device that will pass current in one direction but not in the other direction can be used as a rectifier. You have already seen one example of this type of device: the vacuum tube. In a vacuum tube, as long as the voltage applied to the plate is positive with respect to the voltage applied to the cathode, the current will flow from the cathode to the plate of the tube. However, if the voltage applied to the plate is negative with respect to the voltage applied to the cathode, there will be no current flow through the tube because current cannot normally flow through the tube from the plate to the cathode. Thus, a two-element or diode tube was used for many years as the rectifier in the power supply of radio and television receivers.

The diode tube is entirely satisfactory as a rectifier, but it does have one big disadvantage. In order to handle the currents required in large radio receivers or in television receivers a rectifier tube with a rather heavy cathode or filament is required. Considerable power must be applied to the heater to heat the large cathode or filament, thereby bringing it to the temperature required for it to emit an abundant supply of electrons. Not only does this increase the power consumed by the equipment; also, a substantial amount of heat is given off by the diode and this, in turn, heats up other parts in the equipment. This often contributes to a shortened life of the other parts.

As we mentioned, diode vacuum tubes were used for many years as the rectifiers in radio and television receivers. However, a number of years ago the selenium rectifier began to replace the vacuum tube as the rectifier in entertainment-type equipment.

A typical selenium rectifier is shown in Fig. 1. A selenium rectifier is made up of a series of selenium discs with a coating of selenium oxide on the surface of one side of each disc. Electrons can flow from the selenium to the selenium oxide quite readily, but they cannot readily flow in the other direction, from the selenium oxide to the selenium. Thus, a selenium rectifier permits current to flow through it in one direction, but offers a high resistance to current flow through it in the opposite direction.

This type of rectifier is often called a dry-disc rectifier: "dry" to distinguish it from earlier rectifiers that used a wet chemical solution, "disc" because it is made up of discs. The square plates that are visible in Fig. 1 are cooling fins. The discs used are usually round and are

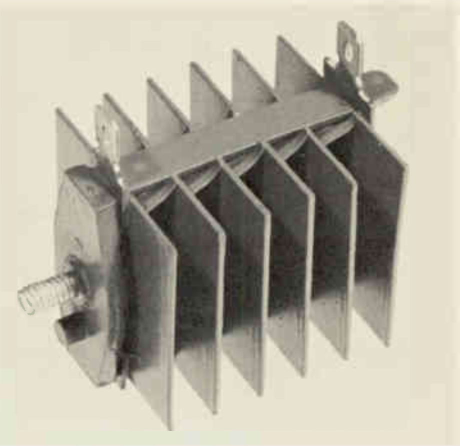

Fig. 1. A typical selenium rectifier designed for use in electronic equipment.

placed between the cooling fins, which are necessary because the rectifier does have some resistance and the current flowing through this resistance produces heat which must be dissipated.

The advantage of the selenium rectifier over the diode tube is that the selenium rectifier does not have a cathode that must be heated, and hence the power required to heat the cathode is saved. In addition, the total heat dissipated into the equipment from the selenium rectifier is somewhat lower than from a tube capable of handling the same current.

Both the vacuum tube rectifier and the selenium rectifier have been replaced in modern radio and television receivers by the silicon rectifier. The silicon rectifier, like the selenium rectifier, does not require any heater power; in addition, a silicon rectifier is much smaller than a selenium rectifier. It has a much lower forward resistance; that is, it offers far less opposition to current flow through it in the forward direction than does a selenium rectifier, and at the same time it has a higher reverse resistance (in other words it will permit a smaller current to flow through it in the reverse direction than a selenium rectifier).

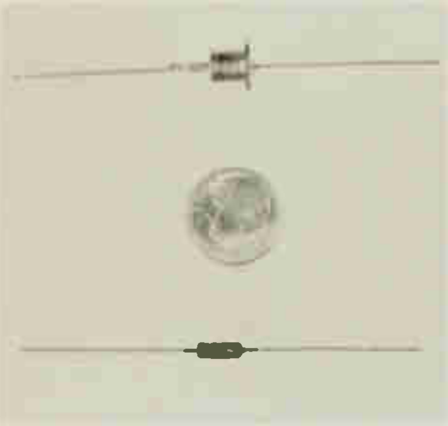

Fig. 2. Two typical silicon rectifiers with a dime between them to show their relative size.

Two typical silicon rectifiers are shown in Fig. 2. The rectifier at the top is called a top-hat rectifier because of its shape. A rectifier of this type and size is capable of handling currents several times those required in a color TV receiver. We have shown a photograph of the two rectifiers with a dime in between them so you can get an idea of the relative size of the two units. The lower rectifier is capable of handling currents of two or three amperes.

In addition to their small size and high current-handling capabilities, silicon rectifiers have another big advantage over selenium and vacuum tube rectifiers due to modern manufacturing techniques: they are relatively inexpensive to manufacture. Furthermore, unless they are overloaded, their life is almost indefinite.

Now, let's see how the various types of rectifiers are used in power supply circuits.

HALF-WAVE RECTIFIERS

You already know that the power supplied by most power companies is ac power and that the voltage supplied has a waveform that is called a sine wave. A typical single cycle is shown in Fig. 3A. A rectifier circuit using a diode tube is shown in Fig. 3B. Let's assume that the waveform shown at A represents the voltage at terminal A of Fig. 3 with respect to the voltage at terminal B. This means that for the first half-cycle (that is, the voltage waveform

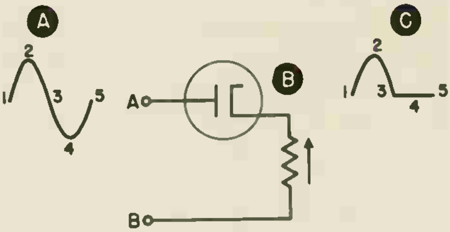

Fig. 3. How current flows in a half-wave rectifier circuit for one ac cycle. We have omitted the rectifier heater to simplify the diagram.

from point 1 to point 3), the plate of the tube will be positive. When the plate of the tube is positive, it will attract electrons from the cathode; therefore, current can flow through the tube.

Thus during the first half-cycle, as the plate voltage starts at point 1 and builds up to point 2, the current through the tube will increase from point 1 to point 2 as shown in Fig. 3C. As the voltage decreases during the first half-cycle from point 2 to point 3, the current through the tube will decrease as shown from point 2 to point 3 in Fig. 3C. When the voltage in Fig. 3A reaches point 3 there will be zero potential between points A and B in the rectifier circuit and current will stop flowing.

During the next half-cycle terminal A will be negative with respect to terminal B. This means that the plate of the tube will be negative; hence no current can flow through the tube. Therefore, the current will be zero (as shown in the waveform in Fig. 3C) as the voltage swings from point 3 to point 5.

The rectifier circuit shown in Fig. 3 conducts when the plate of the tube is positive. Since this occurs during one half the time of each cycle then the rectifier conducts during one half of the cycle but not during the other half. As a result, the rectifier is called a half-wave rectifier. If we operate this type of rectifier from a 60-cycle power line, we will get 60 current pulses through the rectifier during one half-cycle and 60 intervals during which there is no current flow through the rectifier.

Another half-wave rectifier is shown in Fig. 4. Here we have shown a solid-state rectifier in place of the tube. This could be either a selenium rectifier or a silicon rectifier -- the same symbol is used for both types.

Notice the schematic symbol used for the rectifier. Also notice that the arrows indicate that the direction of current flow through the circuit is opposite to the direction in which the arrow points in the schematic symbol. The reason for this is that in the early days of electricity, scientists thought that current flowed from positive to negative. Therefore, this symbol was designed to show the direction in which current flowed. But it was discovered later that current flow was actually electron flow and that it flowed from negative to positive, a direction opposite from that in which the early scientists thought it flowed. Although we know current flow is from negative to positive, we still use the same symbol; it has never been changed so that the arrow is actually pointing in the direction opposite to the direction of electron flow.

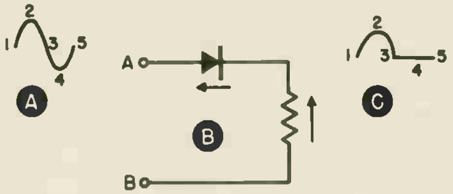

Fig. 4. A half-wave selenium rectifier circuit.

In a power supply of this type using a selenium rectifier, with terminal A positive with respect to terminal B, the selenium rectifier will offer only a low resistance to the flow of current through it; therefore, current flows in the circuit from B through the load and through the rectifier and back to terminal A. During the next half-cycle, when terminal A is negative with respect to terminal B, the selenium rectifier will offer a very high opposition to the flow of current through it so that there will be little or no current flow through the load (as shown in Fig. 4C).

We mentioned that the schematic symbol for the rectifier in Fig. 4 also represents a silicon rectifier. If a silicon rectifier is used, the rectifier will simply consist of a PN junction. The P-type material will be on the side represented by the arrow and the N-type material by the flat line. With a PN junction rectifier in the circuit when terminal A is positive and terminal B is negative, we will have a positive voltage applied to the P side of the junction and a negative voltage applied to the N side of the junction. The negative voltage will repel electrons from the N side of the junction across the junction into the P-type material. Electrons will be attracted through the P-type material by the positive potential applied to it. In other words, there will be a forward bias placed across the junction and current can readily flow through the rectifier because the carriers can cross the junction.

During the next half-cycle when the polarity reverses, terminal A will be negative and terminal B positive. Thus there will be a negative voltage, applied to the P side of the junction, which will repel electrons and prevent them from crossing the junction. At the same time there will be a positive voltage, applied on the N side of the junction, which will prevent any holes from the P side crossing the junction. In other words, there will be a reverse bias placed across the junction; hence the carriers cannot cross the junction and there will be no current flow through the circuit.

Of the three types of half-wave rectifiers, the silicon-type rectifier is the most widely used in modern equipment because of its small size, low cost and very low forward voltage drop.

Sometimes, in order to operate a piece of electronic equipment, a higher voltage is required than can be obtained directly from the power line. Under these circumstances a step-up transformer may be used to step up the voltage as shown in Fig. 5. The secondary-to-primary turns-ratio is simply adjusted to provide the required voltage step-up. A half-wave rectifier is then used as shown to rectify the ac and change it to pulsating dc. The operation of the half-wave rectifier is exactly the same in the circuit as

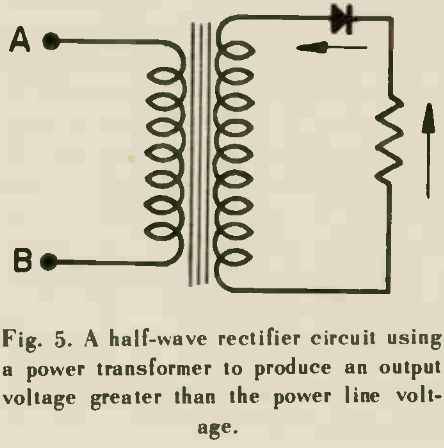

Fig. 5. A half-wave rectifier circuit using a power transformer to produce an output voltage greater than the power line voltage.

it was in the preceding circuits; however, the rectifier will have to have a higher voltage rating to make up for the fact that it is being used in a higher voltage circuit.

The disadvantage of the circuit shown in Fig. 5 is that power transformers are comparatively expensive. By means of the circuit shown in Fig. 6 a voltage approximately twice the voltage obtainable from the half-wave rectifier circuits shown in Figs. 3 and 4 can be obtained. This circuit can be operated directly from the power line and is known as a voltage-doubler circuit.

The operation of this circuit is quite simple. During one half-cycle terminal A will be negative with respect to terminal B. During this half-cycle electrons flow from A into the side of the capacitor C1 marked with the minus sign. The electrons flowing into this side of the capacitor force electrons out of the other side leaving a positive charge on this side of C1. The electrons leaving the positive side of C1 flow through the rectifier D1, back to side B of the power line which is positive and which will attract electrons. Thus, during this half-cycle, when terminal A is negative with respect to terminal B, capacitor C1 is charged with the polarity shown. The peak charge on C1 will be equal to the peak value of the ac input voltage.

During the next half-cycle, when terminal A is positive with respect to terminal B, we have a situation where the voltage between terminals A and B is effectively placed in series with the voltage charging capacitor C1. These series-connected voltages will cause a current to flow through the load and through D2. During this half-cycle terminal A is positive with respect to terminal B. This means that terminal B is negative. Electrons flow from terminal B through the load and through D2. They are attracted by a positive voltage which is equal to the voltage across C1 plus the line voltage. Thus the peak voltage that can be developed across the load will be equal to twice the peak line voltage.

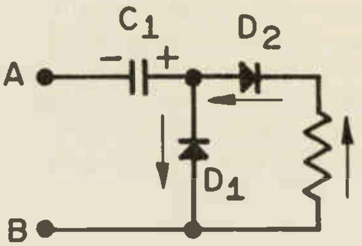

Fig. 6. A half-wave voltage-doubler circuit.

You might wonder why the current flows through only one rectifier during each half-cycle. During the first half-cycle, when terminal A is negative with respect to terminal B, the electrons flowing through D1 and charging C1 cannot flow through D2 because the diode is connected in such a way as to prevent current flow through them in that direction. Similarly, during the next half-cycle, when terminal B is negative and terminal A is positive, current cannot flow through D1 because it would have to flow through it in the reverse direction. Current can flow through the diodes only in the direction shown and it will flow through D1 during one half-cycle and through D2 during the other half-cycle.

This type of power supply is known as a half-wave doubler circuit. It is called a voltage-doubler circuit because the voltage across the load is effectively double the line voltage.

It is called a half-wave circuit because there is a current pulse to the load during only one half of each cycle. The half-wave voltage-doubler circuit is widely used in modern radio and television receivers. It's a very important circuit and you should be sure you understand how it works before leaving it.

When a half-wave rectifier is used in the power supply, the current will flow through the rectifier in a series of pulses. With a 60-cycle power supply line, there will be 60 pulses per second: one pulse during each positive-half cycle and nothing during each negative-half cycle. The net result is that you will have current flowing through the rectifier for no more than half the time. This results in a pulsating dc output from the rectifier that is rather difficult to smooth out to the pure dc required in most equipment to operate the tubes and/or transistors. A somewhat better arrangement is the full-wave rectifier that passes current during both halves of the ac voltage cycles.

FULL-WAVE RECTIFIERS

A typical full-wave rectifier circuit is shown in Fig. 7. Notice that the tube used is a twin diode tube. The tube has two plates and a single filament which is used with both plates. In operation, this tube acts as two separate diode tubes.

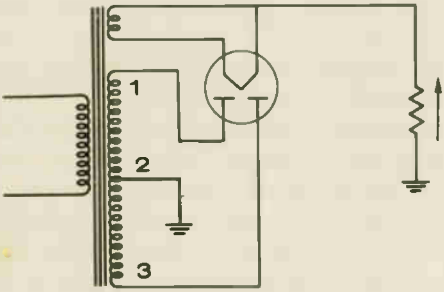

Fig. 7. A full-wave rectifier circuit using a single rectifier tube with two plates.

The power transformer used in the rectifier circuit has three windings. The primary winding is the winding that connects to the power line. A low-voltage winding is used to provide the current required to heat the filament of the rectifier tube. It serves no other purpose as far as the operation of the rectifier circuit is concerned. This winding is often referred to as the filament winding.

The high-voltage winding on the transformer is the winding that will supply the pulsating current to the load resistor. Notice that this winding has a center tap. In operation, one half of the winding first supplies the current and then, during the next half-cycle, the other half of the winding supplies current to the load.

We can see how this rectifier circuit works if we consider one half-cycle during which terminal 1 of the high-voltage secondary is positive. This means that terminal 2 will be negative with respect to terminal 1 and terminal 3 will be even more negative. Electrons will leave the center tap, terminal 2, and flow through ground to the load resistor. They will flow through the load resistor to the filament of the rectifier tube and then be attracted to the plate connected to terminal 1 because this plate has a positive voltage applied to it. No electrons will flow to the other plate because this plate is negative with respect to both terminals 1 and 2.

During the next half-cycle, the polarity of the secondary voltage will reverse. At this time terminal 3 will be positive, terminal 2 negative with respect to it, and terminal 1 even more negative. During this half-cycle electrons will leave terminal 2 and flow through ground to the load, through the load and to the filament of the rectifier tube, and then to the plate connected to terminal 3 because this plate now has the positive voltage applied to it. No electrons will flow to terminal 1 because terminal 1 is negative with respect to both terminals 2 and 3.

Notice that with the full-wave rectifier circuit we get a current pulse through the load resistor during each half-cycle. This means that for a 60-cycle power line we will get 120 pulses of current through the load. Since there is current flowing through the load during each half-cycle, this type of rectifier produces an output that is much easier to filter to a smooth dc than the output from a half-wave rectifier.

Either selenium rectifiers or silicon rectifiers can be substituted in this type of circuit in place of the rectifier tube. This type of circuit was widely used in older television receivers along with vacuum tubes. Modern TV receivers use silicon rectifiers and frequently use bridge-rectifier circuits or voltage-doubler circuits in place of this circuit.

BRIDGE-RECTIFIER CIRCUITS

One of the disadvantages of the full-wave rectifier circuit shown in Fig. 7 is that it requires a transformer with a center-tapped secondary. The total voltage across the entire secondary winding is actually twice the voltage between the center tap and either end of the secondary winding. This type of transformer is more expensive to manufacture than a transformer without a center tap because twice as many turns are required on the secondary to get the required voltage.

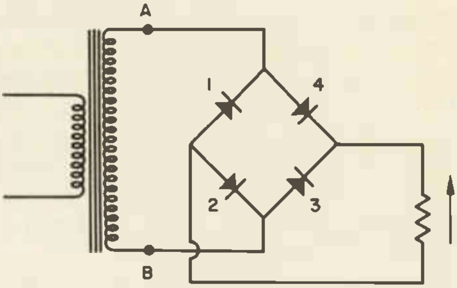

Fig. 8. A bridge-rectifier circuit.

A circuit that gets around the requirement of a center-tapped secondary is shown in Fig. 8. This is called a bridge-rectifier circuit; it is also often called a full-wave bridge-rectifier circuit because current flows to the load during each half-cycle.

A quick look at the circuit immediately shows us that four rectifiers are required in a circuit of this type. At one time this was a disadvantage because of the cost of rectifiers, but silicon rectifiers are comparatively inexpensive today and it is usually more economical to use the extra two silicon rectifiers and avoid the center tap on the secondary winding of the power transformer. The power transformer shown in Fig. 8 would be far more economical to manufacture than the one shown in Fig. 7.

The operation of the bridge rectifier is comparatively simple. When terminal A is positive and terminal B is negative, current will flow from terminal B through the rectifier marked 2 on the diagram and then through the load to the junction of rectifiers 3 and 4. It will then flow through rectifier 4 back to terminal A on the transformer. During the next half-cycle, when terminal A is negative and terminal B is positive, current will flow from terminal A on the transformer through the rectifier marked 1 on the diagram and then through the load back to the junction of rectifiers 3 and 4. This time the current will flow through rectifier 3 back to terminal B of the power transformer.

Notice that during each half-cycle current flows through two of the rectifiers. During one half-cycle it will flow through rectifiers 2 and 4 and during the other half-cycle it will flow through rectifiers 1 and 3. Also notice that current flows during both half-cycles; therefore, this bridge rectifier is a full-wave rectifier.

Bridge rectifiers have been used in television receivers where comparatively high operating voltages and high currents are required. The bridge circuit eliminates the need for the center tap on the power transformer secondary winding and thus reduces the cost of the transformer. The voltage regulation (the ratio of the full-load voltage to the no-load voltage) obtainable with this type of power supply is as good as the regulation that can be obtained from the full-wave rectifier circuit shown in Fig. 7.

FULL-WAVE VOLTAGE DOUBLERS

A full-wave voltage-doubler circuit is shown in Fig. 9. One advantage of this type of circuit is that we get the same load voltage as you have in a circuit like the bridge rectifier shown in Fig. 8, although only half as many turns are required on the secondary of the power transformer. This will result in a savings in the cost of the power transformer. Another advantage of this type of circuit is that only two rectifiers are required instead of the four required in the bridge-rectifier circuit.

The operation of the full-wave voltage-doubler circuit is quite simple. During one half-cycle terminal A of the power transformer secondary will be negative and terminal B will be positive. During this half-cycle current flows from terminal A through diode D2 to the capacitor C2 charging the capacitor as shown. Electrons flow into the negative side of the capacitor and out the positive side back to terminal B of the power transformer. During the next half-cycle, terminal B of the power transformer secondary will be negative and terminal A will be positive. During this half-cycle electrons leave terminal B of the power transformer and flow into capacitor C1. They flow into the side of the capacitor marked with the minus sign and force electrons out of the plus side. Electrons leaving the plus side flow through diode D1 back to terminal A of the power transformer, which is positive.

The capacitors C1 and C2 are connected in series and they supply the voltage to the load. The capacitors are charged by the current flowing

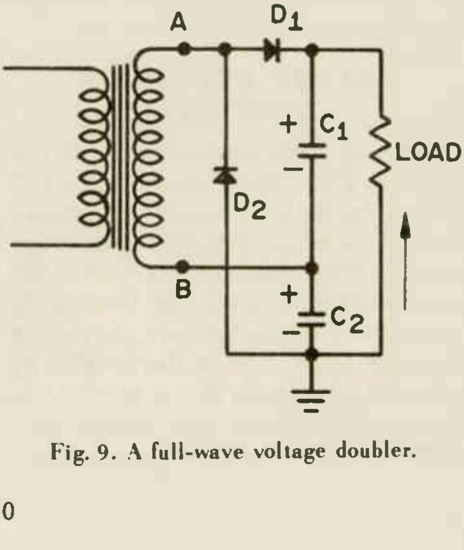

Fig. 9. A full-wave voltage doubler.

through the diodes, and since there is a charging pulse each half-cycle we will get 120 charging pulses from a 60-cycle power line. Since there is a charging pulse during each half-cycle, the circuit is a full-wave rectifier. The actual voltage that will be available across C1 and C2 in series will depend upon the power transformer secondary resistance, the resistance of the diodes when they are conducting, the size of the two capacitors, and the size of the load. As the resistance of the load increases, the current that will flow through the load decreases, and the charge on each capacitor becomes closer to the peak value of the ac voltage between terminals A and B.

Notice that in the diagram we have shown the direction of current flow through the load. The load current is supplied entirely by the charged capacitors C1 and C2. As the capacitors supply current to the load, electrons leave the negative plate of C2 and flow through the load in the direction shown. These electrons flow into the positive side of C1 forcing electrons out of the negative side into the positive side of C2. Thus the current flow through the load tends to reduce the charge across the capacitors. Of course, during each half-cycle one of the diodes conducts to build the charge across one of the capacitors up towards the peak value of the line voltage.

While this type of rectifier circuit offers some advantages over the circuits shown in Figs. 7 and 8, it does not have as good voltage regulation as they have. However, by using capacitors of large capacity for C1 and C2, and with modern silicon rectifiers that have a very low resistance when they are conducting, reasonably good voltage regulation can be obtained from this type of power supply. You will find the power supply widely used both in monochrome and color television receivers. Be sure you understand how it operates because you will run into it frequently.

In comparing this power supply with the half-wave doubler circuit shown in Fig. 6, we immediately see that the full-wave doubler circuit is best suited to equipment where a power transformer is used. The half-wave voltage-doubler circuit is widely used in equipment where no power transformer is used.

SUMMARY

The rectifier circuits that we have discussed in this section of the lesson are extremely important. As you know, the power supplied by the power companies is alternating current and the tubes and transistors in electronic equipment require direct current for their operation. Therefore, equipment designed to operate from the power line must use some type of rectifier to convert the alternating current to direct current. One of the circuits shown in this section of the lesson is likely to be found in any type of electronic equipment you will service.

The half-wave rectifier circuit shown in Fig. 5 is perhaps the most widely used. All table model radio receivers use this type of rectifier circuit without a power transformer so that the receiver can operate directly from the power line. The half-wave voltage-doubler circuit shown in Fig. 6 is widely used in television receivers where operating voltages higher than those that can be obtained directly from the power line are needed. In some of the older radio receivers and many older television receivers a full-wave rectifier circuit such as shown in Fig. 7 will be found. This type of circuit was used almost exclusively in television receivers before the development of low-cost selenium and silicon rectifiers.

The bridge-rectifier circuit shown in Fig. 8 is used in many television receivers, particularly large television receivers where fairly high voltages and high currents are required. This type of circuit is also used in some transistorized equipment where lower than line voltages are required. In this instance, instead of being a step-up transformer, the transformer will be a step-down transformer that steps the line voltage down to a low value. The bridge-rectifier circuit is then used so that good voltage regulation can be obtained and so that at the same time a comparatively large current can be taken from the power supply.

The full-wave voltage-doubler circuit has been used in many television receivers -- in those which use power transformers where voltages higher than the line voltage are required -- yet at the same time, the transformer serves primarily as an isolation transformer. In other words, the secondary voltage is approximately equal to the primary voltage. The higher voltage required is obtained by the voltage-doubling action. The output from the full-wave doubler circuit is somewhat easier to filter or smooth out than the output from the half-wave doubler circuit, because with the former we have 120 pulses per second through the load and with the latter we have only 60 pulses per second.

Before leaving this section regarding rectifier circuits, why not try to draw the circuits yourself? It would be worthwhile, and you don't have to draw them from memory -- copying them first from the book will help you to remember what they look like. Eventually, you'll be able to draw them from memory and recognize various circuits on the schematic diagram of any radio or TV receiver or piece of electronic equipment you may encounter.

After reviewing this section, do the following self-test questions.

SELF-TEST QUESTIONS

(a) In a half-wave rectifier circuit such as the circuit in Fig. 5, how many current pulses per second will there be through the load when the power line frequency is 60 pulses per second?

(b) What is the disadvantage of a half-wave rectifier circuit?

(c) What is the purpose of the diode marked D1 in the half-wave voltage-doubler circuit shown in Fig. 6?

(d) Why is the circuit shown in Fig. 7 called a full-wave rectifier circuit?

(e) What is the disadvantage of the full-wave rectifier circuit shown in Fig. 7?

(f) What are the advantages of the bridge-rectifier circuit shown in Fig. 8?

(g) What advantage does the voltage-doubler circuit shown in Fig. 9 have over the voltage-doubler circuit shown in Fig. 6?

(h) What are the advantages and disadvantages of the full-wave voltage doubler over the bridge-rectifier circuit?

Filter Circuits

The output from the rectifiers we discussed in the preceding section is not pure dc. Instead, it is pulsating dc: "direct" because it flows in only one direction, "pulsating" because it is varying in amplitude rather than flowing steadily. A pulsating dc voltage is a voltage that does not change polarity, but does change in amplitude. The voltage at the output of a half-wave rectifier will be zero during one half of each cycle and swing in a positive direction during the other half of each cycle.

Looking at the half-wave circuits shown in Fig. 3 and 4, you can consider the rectifier more or less as a switch. During one half-cycle the switch is closed so that the load is connected directly across the power line, and during the other half-cycle the switch is open so that no voltage is applied to the load. The voltage across the load in a half-wave rectifier circuit looks like Fig. 10A. The first half-cycle represents the cycle when the switch is closed and the load is connected directly across the power line, and the second half-cycle represents the cycle when the switch is open and there is no voltage applied across the load. We have shown what the voltage across the load will look like for four cycles in Fig. 10A.

In a full-wave rectifier circuit such as shown in Fig. 7, you have two switches. During one half-cycle one switch closes and connects the load across one half of the power transformer secondary; then, during the next half-cycle, the other switch closes and connects the load across the other half of the transformer secondary.

In the bridge rectifier shown in Fig. 8 two rectifiers act as switches and close to connect the load across the transformer secondary during one half-cycle; then during the next half-cycle the other two switches close, giving the effect of turning the load around so that the current flows through it in the same direction and the voltage applied across the load has the same polarity. The output from a full-wave rectifier circuit will produce a voltage across the load that looks like Fig. 10B.

As you can see from the waveforms shown in Fig. 10, the output taken directly from the rectifier is not a pure dc. There is a voltage, but the voltage drops to zero, builds up to the maximum value, and drops to zero again. In the half-wave circuit it remains at zero for a half-cycle and then builds up again in a positive direction. In the full-wave rectifier circuit the voltage builds up across the load during each half-cycle. In either case, this pulsating voltage will cause a pulsating current through the load which is entirely unsuitable for use in electronic equipment. Fortunately, there are convenient methods that can be used to filter or smooth this voltage to a pure dc voltage.

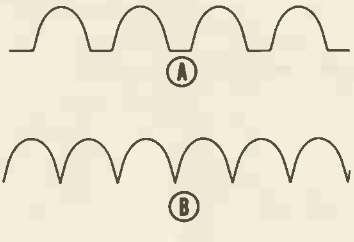

Fig. 10. Output voltage from half-wave and full-wave rectifier.

The pulsating dc voltage at the output of the rectifier is actually a dc voltage with an ac voltage, called a ripple voltage or a hum voltage, superimposed on it. The circuits used to get rid of this ripple or hum voltage are called filter circuits. There are a number of different types of filter circuits found in electronic equipment; in this section we will cover some of the circuits more commonly used.

THE SIMPLE CAPACITOR CIRCUIT

One of the simplest filters is the single capacitor filter shown in Fig. 11. In Fig. 11A we have shown a rectifier circuit using a tube and in Fig. 11B a rectifier circuit using a silicon rectifier. Notice that the circuits are practically identical -- we simply changed the rectifying devices in the two circuits.

The simple capacitor-type filter is sometimes used in circuits where the current drained or taken from the power supply is low. If the rectifier must supply high current to the circuit, this type of filter is generally unsatisfactory because there will be too much ripple or hum present across the load. In other words, the simple filter is simply not capable of eliminating all the ac or ripple voltage present at the output of the rectifier.

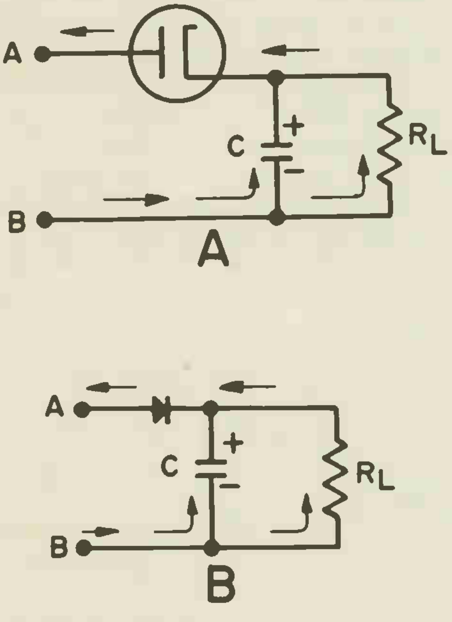

Fig. 11. A simple capacitor-type filter.

Both circuits shown in Fig. 11 work in the same way. Current flows through the rectifier during one half-cycle, as in the half-wave rectifier circuits we studied previously. When terminal A is positive, electrons will flow from terminal B through the load and through the rectifier back to terminal A. At the same time, electrons will flow into the negative side of the capacitor and out the positive side and through the tube or silicon rectifier back to terminal A. The capacitor eventually will be charged to a value almost equal to the peak line voltage. This will happen when the ac line voltage reaches its peak value with terminal A at its peak positive voltage with respect to terminal B.

Now, if the load on the rectifier circuit is light (that is, if the load resistor is a high resistance that draws very little current), as the ac input voltage between terminal A and B drops, capacitor C will begin to supply the current required by the load. Electrons will start to leave the negative side of the capacitor and flow through the load resistor back to the positive side of the capacitor. They will continue doing this as the ac voltage drops to zero and remains at zero during the next half-cycle and starts to build up again in the positive direction. The capacitor will continue to supply current to the load as long as the voltage across the capacitor is greater than the ac input voltage. Eventually, the input voltage will reach a value greater than the capacitor voltage; then we'll get a current flow into the capacitor and through the rectifier to recharge the capacitor.

In Fig. 12 we have shown the ac input voltage. Notice that during the first half-cycle between points 1 and 2 in Fig. 12A the ac voltage is increasing in a positive direction. Let's assume that terminal A in Fig. 11 is becoming positive with respect to terminal B. This explanation applies to both of the two circuits shown. During this first half-cycle the capacitor is charging and follows a curve as shown from point 1 to point 2 in Fig. 12B. Now, as the ac cycle drops from point 2 to point 3 on curve A in Fig. 12, the voltage drops faster than the capacitor discharges. During the interval from point 2 to point 5 and almost to point 6, as shown in Fig. 12A, the capacitor discharges very little. The discharge is shown on the curve from point 2 over to the number 5 on curve B. At this point the ac input voltage exceeds the capacitor voltage, so the capacitor is recharged again.

In circuits where the drain or load current is low, the capacitor will discharge very little between current pulses that recharge it so that the voltage across the capacitor and hence the voltage across the load remain almost constant. Of course, as the requirements of the load increase, the capacitor will discharge more so that there will be more of a voltage drop across the capacitor and across the load than in circuits where current drain is low.

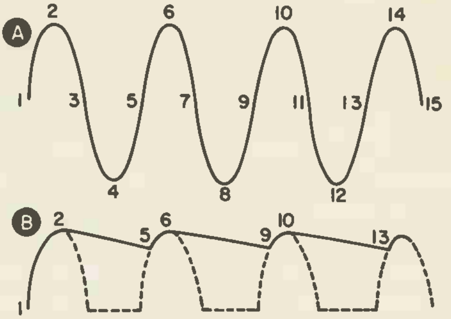

Fig. 12. Voltage waveshapes for a simple capacitor filter. (A) Input voltage; (B) output voltage.

There are several important points you should notice in the circuits shown in Fig. 11. Notice that the current does not flow during an entire half-cycle, but flows only when the line voltage exceeds the voltage across the capacitor. This may be for a very short interval if a load is a high resistance and draws very little current, or it may be for a sizable portion of a half-cycle if the current is a low resistance and draws a high current from the power supply. However, since the current flows through the rectifier in pulses, then the current pulse through the rectifier must be many times the average dc current flowing through the load. This is because the pulse or current that flows through the rectifier during the interval in which the rectifier is conducting must supply enough current to the capacitor to charge the capacitor and make up for the current it is going to supply for the remainder of the cycle.

When the rectifier is not conducting it is because the voltage across it is what we call a reverse voltage. In other words, it has a polarity opposite from that which the rectifier needs to conduct. In the case of the vacuum tube circuit this means that the plate of the tube is negative with respect to the cathode; in the case of the silicon rectifier, that there is a reverse bias across the junction.

One of the important characteristics of a rectifier is the maximum peak reverse voltage that can be placed across the rectifier before it breaks down. In the circuit shown in Fig. 11 the capacitor will be charged as shown and the charge can equal the peak line voltage. During the next half-cycle, when the polarity of the input voltage reverses, terminal A will be negative and terminal B will be positive. When this voltage reaches its peak, the peak reverse voltage across the rectifier will be equal to twice the peak line voltage. The rectifier must be able to withstand this voltage without breaking down. This important characteristic, by which rectifiers are rated, is usually referred to as "PRV" (peak reverse voltage), although it may also be called "PIV" (peak inverse voltage). The two are simply the maximum reverse or inverse voltages that can be applied across the rectifier without its breaking down. In circuits such as those shown in Fig. 11, the PIV should be considerably higher than twice the peak line voltage in order to allow a reasonable safety factor.

As we mentioned previously, the simple capacitor-type filter shown in Fig. 11 is usable only where a small current is required by the load. If the current required is small, the output capacitor can be made large enough so that it discharges very little between pulses. If the current required by the load is high, on the other hand, then the capacitor will discharge appreciably between charging pulses, resulting in a varying voltage applied to the load. This is essentially the same as applying dc mixed with ac to the load. Additional filtering is required in applications of this type in order to eliminate ac so that we will have pure dc across the load.

AN R-C FILTER

An improved filter, which is often called a pi filter because it looks like the Greek letter pi (π), is shown in Fig. 13. You will notice that this filter consists of two capacitors, C1 and C2, and a filter resistor, R1.

The operation of the half-wave rectifier and capacitor C1, which is called the input filter capacitor, is the same as in the simple capacitor filter shown in Fig. 11. The rectifier tube passes current pulses to charge capacitor C1 with the polarity indicated on the diagram. However, if the

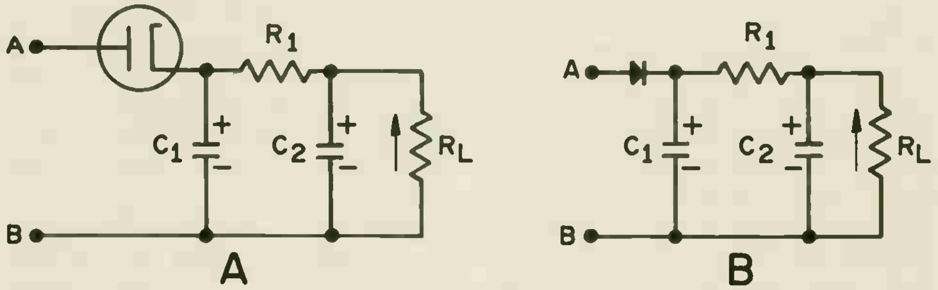

Fig. 13. An R-C pi-type filter.

load resistance R_L is low enough to draw appreciable current from the supply, then the voltage across C1 will discharge appreciably during the portion of the cycle when the rectifier tube is not conducting. Thus, we have dc with an ac superimposed on it across C1.

Now, to see the action of R1 and C2, let us first consider how the capacitor C2 reacts to ac and to dc. Remember that a capacitor is a device that will not pass dc -- it can be charged so that a dc voltage will exist across it, but applying dc to the plates of the capacitor will not cause a current to flow through it. Although electrons cannot cross through the dielectric of a capacitor, however, applying ac to the dielectric of a capacitor yields the effect of a current flowing through it. This is due to the fact that electrons will flow first into one plate and then into the other as the polarity of the ac voltage reverses.

You will remember from your study of capacitors that a capacitor offers what is called capacitive reactance (or opposition) to the flow of ac through it. The exact reactance that any capacitor will offer to the flow of ac through it is given by the formula:

$$Xc = \frac{1}{6.28 \times f \times C}$$

You can see from this formula that the larger the value of the capacitor, the lower the capacitive reactance will be to an ac voltage of a particular frequency. In Fig. 14A we have shown how the filter consisting of R1 and C2 reacts to dc; in Fig. 14B, we have shown how it reacts to ac.

As you know, a "perfect" capacitor will not pass dc -- although no capacitor is really perfect because there will always be a small dc current (called a leakage current). In other words, the capacitor offers a very high resistance to dc, so we have shown it as resistor R_{C2}. Most of the dc voltage applied to the input of this filter network will appear across the capacitor, and there will be very little dc dropped across the resistor R1. The exact drop across this resistor will depend upon the size of the resistor and the current drawn by the load.

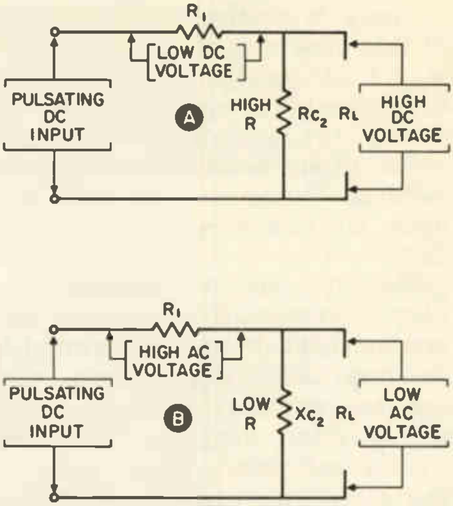

Fig. 14. Equivalent circuits showing the reaction of an R-C filter to dc at A, and to ac at B.

Now look at Fig. 14B which shows the reaction of the circuit to an ac voltage. The capacitor has a very low reactance to ac, so most of the ac voltage will be dropped across R1, because the resistance of R1 is much higher than the reactance (X) of C2. R1 and C2 act as a voltage divider network with most of the ac being dropped across R1 because its resistance is much higher than the reactance of C2.

There is another way of looking at this type of power supply which may help you see exactly what is happening in the circuit. Refer back to Fig. 13; the explanation applies to the circuit using the vacuum tube rectifier shown at A and to the one using the silicon rectifier shown at B.

When terminal A is positive with respect to terminal B, the diode will conduct and current can flow through the diode and through the load. During this part of the cycle electrons will flow into the plates of C1 and C2 marked with a minus sign. At the same time electrons will flow out of the other plate of both capacitors. Electrons leaving the positive side of C1 will flow directly through the diode being attracted by the positive voltage at terminal A. Because the resistance of the rectifier is low, C1 can charge up to a value almost equal to the peak ac voltage. However, the electrons leaving the positive side of C2 must flow through the filter resistor R1. Thus, capacitor C2 cannot charge to as high a voltage as capacitor C1.

When the ac input voltage drops so that the diode no longer conducts, capacitors C2 and C1 begin supplying the power required by the load. However, capacitor C1 is charged to a higher voltage than capacitor C2. Hence, capacitor C1 begins supplying power to the load and also tries to charge capacitor C2. Since electrons flowing from the negative side of C1 to the positive side must flow through filter resistor R1, the attempt of these electrons to charge C2 and flow through the load resistor will be somewhat restricted by R1. The net effect is that the resistor R1 prevents C2 from charging to as high a peak voltage as it would if R1 were not on the circuit. Because C1 charges to a higher voltage than C2, and while discharging tends to charge C2, the voltage across C2 is more nearly constant than the voltage across C1.

AN L-C FILTER

The disadvantage of the resistor-capacitor type of filter shown in Fig. 13 soon becomes apparent if you consider the size of the resistor and capacitor needed to obtain effective filtering and also the effect that the high value of resistance in the circuit has on the dc voltage present.

Consider Fig. 13 again for a minute. Suppose that the ac component of the pulsating dc across C1 is 10 volts and that the maximum ac component that can be applied to the load is only 1 volt. This means that the filter network consisting of R1 and C2 must produce a 9-to-1 voltage division. In other words, of the 10 volts ac appearing across C1 we must drop 9 volts across R1 and 1 volt across C2. This means that the resistance of R1 must be about 9 or 10 times the reactance of C2.

A 25-mfd capacitor (which is fairly large, particularly if it must be built to withstand high voltages), has a reactance of about 100 ohms at a frequency of 60 cycles. If we used such a capacitor for C2, then the resistance of R1 would have to be 10 times its reactance, or about 1000 ohms. If the current drawn by the load is 100 milliamperes, then the voltage drop across R1 due to the load current flowing through it will be 1000 ohms times .1 amp (100 ma), or 100 volts. This means that we will be losing 100 volts of our dc voltage across R1. Furthermore, the power being wasted by this resistor will be

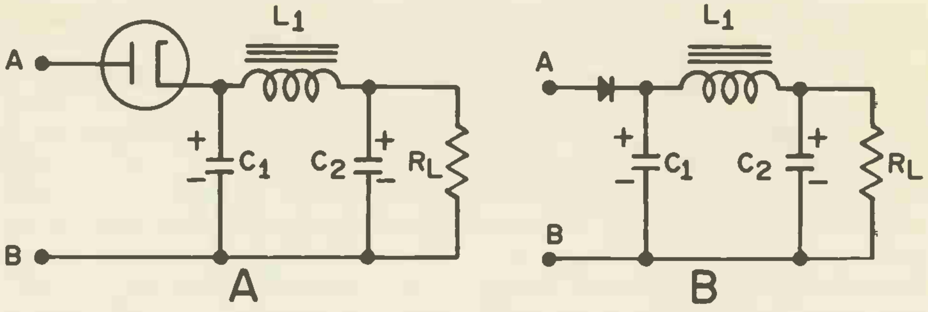

Fig. 15. An L-C filter.

equal to the voltage across it times the current flowing through it, which is 100 × .1, or 10 watts. You can see that we have an appreciable voltage drop and a sizable amount of power wasted by this resistor.

In some cases the current drawn through the filter resistor is not so high that the voltage drop across the resistor cannot be tolerated. Thus you will see this type of filter used in equipment when the current taken from the power supply is moderate. In equipment when the current drawn is high, a different type of filter is used. Such a filter is shown in Fig. 15. Notice that this circuit is identical to Fig. 13, except that we have substituted an iron-core choke for R1. The action of this filter network is quite similar to that of the filter network shown in Fig. 13. Again, capacitor C1 is charged by the rectifier and because there is no resistance in the circuit other than the rectifier resistance, it charges to a fairly high value. Just as before, however, the voltage across it will be pulsating (the equivalent of dc with ac superimposed on it).

Now consider the reaction of the choke to ac and dc. You will remember that a choke has inductance, and an inductance offers reactance to the flow of ac through it. At the same time the only opposition that the choke will offer to the flow of dc through it is due to the resistance of the wire used to wind the coil. By using a large size wire, this resistance can be kept quite low. The choke may have a dc resistance of 100 ohms or less and at the same time have a reactance of several thousand ohms to the 60-cycle ac applied to it.

The reaction of the L-C filter to dc is shown in Fig. 16A, and the reaction to ac is shown in Fig. 16B. In 16A we see that as far as the dc is concerned, the choke acts as a

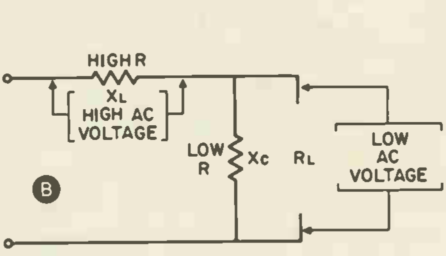

Fig. 16. Equivalent circuit showing the reaction of an L-C filter to dc at A, and to ac at B.

low resistance while the capacitor acts as a very high resistance. Thus, we have practically all of our dc voltage appearing across the capacitor and very little of it being lost across the choke. However, as shown in 16B, the choke acts as a high resistance to the ac while the capacitor acts as a low resistance. Thus, most of the ac voltage will appear across the choke and very little of it will appear across the capacitor.

There is another way of looking at the action of the L-C filter. We can consider the charging of the capacitors and the opposition offered by the choke more or less in the same way as we considered the action of the R-C filter in Fig. 13. During the first half-cycle, when terminal A of either rectifier circuit is positive and terminal B is negative, the rectifier will conduct. Electrons will flow from terminal B into the sides of C1 and C2 marked with a minus sign. These electrons will force electrons out of the positive side of C1 and they will flow through the rectifier with little or no opposition. However, the electrons leaving the positive side of C2 will encounter opposition in the choke. This is because at the instant when the electrons first try to get through the choke there is no magnetic field built up in the choke. You will remember that a choke is a device that opposes any change in current flowing through it. Therefore, the choke tries to keep the electrons leaving the positive side of C2 from flowing through it. Eventually this opposition offered by the choke is overcome, a magnetic field is built up in the choke, and some of the electrons can flow through the choke and capacitor C2 will be charged. However, the voltage to which C2 is charged will not be as high as the voltage to which C1 is charged because of the opposition of the choke.

When the ac input voltage drops below the voltage to which C1 is charged, the rectifier will no longer conduct and no current can flow through it. Now C1 and C2 and choke L1 must supply the current needed by the load. C2 does this by attempting to discharge. C1 also tries to discharge to charge C2 and to supply part of the current required by the load. At the same time there is a magnetic field built up in the choke L1 which does not collapse instantly but instead tries to keep current flowing in the direction it was flowing when the rectifier was conducting. It too helps to maintain the current flow through the load RL. Thus in this type of filter we have energy stored in three places: the capacitors C1 and C2 (as we did in the circuit in Fig. 13), and in the magnetic field of choke L1.

In the circuits shown in Fig. 15, the rectifier tube in Fig. 15A offers a certain amount of resistance to the flow of current through it. In addition, the rectifier tube has a cathode which must be heated by a heater. It takes some time for the cathode to come up to operating temperature; when a tube first starts conducting, the cathode is below normal operating temperature, and the tube offers a higher resistance to the flow of current through it than it does when the tube reaches its full operating temperature. Thus when the power supply is first turned on and the tube reaches a temperature at which the cathode begins to emit electrons, the tube offers considerable resistance to the flow of current through it. This limits the charging current through the tube that charges the input filter capacitor C1. In a matter of a few seconds capacitor C1 is charged and from then on the current that must flow through the tube is within the tube's capabilities.

In the circuit shown in Fig. 15B, however, the silicon rectifier does not have a cathode which must be heated -- as soon as the power is turned on the rectifier begins to conduct to charge the input capacitor C1. If you turn the equipment on at the peak of the ac cycle there will be a very high voltage immediately impressed across C1 and a very high current will flow through the rectifier. As a matter of fact, the current might be so high that it could burn out the rectifier. Even if the power is turned on when the ac voltage is at zero, a high current will flow through the diode to charge C1 as the voltage rises to a peak value with terminal A positive with respect to terminal B. If C1 is large enough, this could burn out the rectifier.

This problem of excessively high charging current can be overcome with the circuit shown in Fig. 17. Here a resistor is connected in series with the silicon rectifier to limit the current flow. In some equipment, this resistor is a fairly low resistance, fixed-value resistor. In other applications, the resistor may be a thermistor. You will remember that a thermistor is a resistor with a negative temperature coefficient. This means that the resistance of the thermistor decreases as its temperature increases.

With a thermistor for the resistor R1 shown in the circuit in Fig. 17, the thermistor will offer a fairly high resistance to current flow when the equipment is first turned on. This will limit the charging current that flows through the diode to charge C1 to a reasonable value. As the current flowing to the thermistor heats the thermistor and its resistance goes down, the charge across capacitor C1 will build up slowly so that the diode current never reaches an excessively high value. By the time the capacitor is fully charged, the thermistor temperature will have increased to a point where the resistance of the thermistor has dropped to a low value so that the thermistor has very little effect on the overall operation of the circuit.

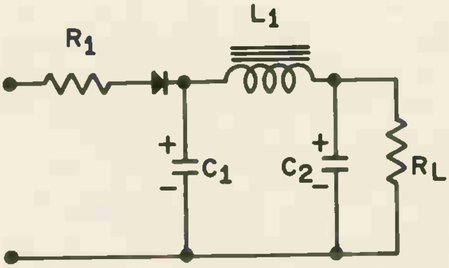

Fig. 17. Power supply with series-limiting resistor.

If you have to service a power supply of this type (where a resistor or a thermistor is used in the circuit in series with a silicon rectifier) and you find that the resistor or thermistor is opened, do not simply short the resistor or thermistor out of the circuit. If you do the chances are that the diode will burn out either the first time that you turn the equipment on or shortly thereafter.

The rectifier tubes used in low power equipment such as radio and television receivers are high vacuum rectifier tubes. However, in transmitters and in industrial applications where high voltages are involved you will often run into mercury-vapor rectifier tubes. Tubes of this type cannot be subjected to high peak currents through them without damaging the tube. A mercury-vapor rectifier tube in the circuit such as shown in Fig. 15A lasts only a short time. We can keep the peak current through the tube down to a safe value by using a somewhat different filter circuit known as a choke-input filter.

CHOKE-INPUT FILTERS

The filter circuits shown in Figs. 15 and 17 are called capacitor-input filters because the rectifier is connected directly to the input filter capacitor. A choke-input filter such as those frequently used with a mercury-vapor rectifier tube is shown in Fig. 18. Here, the rectifier tube is connected to a filter choke rather than a capacitor. Power supplies of this type will be found in radio and television transmitters and in industrial applications where comparatively high voltages are encountered.

It is easy to see how this type of filter works when we remember that the pulsating dc at the output of the rectifier tube is actually dc with ac superimposed on it. The choke offers little or no opposition to the flow of dc through it. On the other hand, the choke offers a high reactance to the flow of ac through it and at the same time the capacitor offers a low reactance to the ac across it. Thus the choke and the capacitor form a voltage divider network for the ac, so that most of the ac is dropped across the filter choke and very little of it appears across the load.

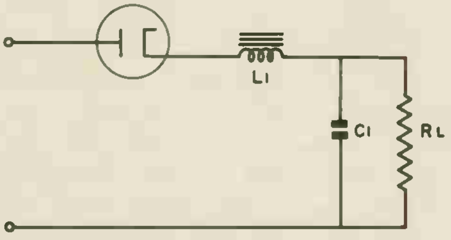

Fig. 18. A choke-input filter.

A more elaborate filter network is the two-section filter shown in Fig. 19. Again, it is a choke-input filter because the first element in the filter network is a choke. This type of filter network is frequently used in power supplies of radio and TV transmitters and of industrial electronic equipment where mercury-vapor rectifier tubes are used.

The choke-input filter has several advantages over the capacitor-input filter, even though the voltage obtained at the output of a choke-input filter is not quite as high as it is at the output of equivalent capacitor-input filters. In other words, if you feed the same pulsating dc into a choke-input filter you will not obtain as high an output voltage for a given load as you can with a capacitor-input filter. However, this type of filter has better voltage regulation than a capacitor-input filter. The voltage regulation of a power supply is the ratio of the full-load voltage to the no-load voltage. With a choke-input filter there is not as great a variation between the no-load and the full-load voltages as there is in the capacitor-input filter.

Another big advantage of the choke-input filter is that the peak current passed by the rectifier tube is held to a reasonable value. In a choke-input filter, the choke offers considerable reactance to any change in current flow through it. Thus, when the rectifier tube tries to conduct current heavily to charge C1 in Fig. 19, the input-filter choke L1 offers considerable reactance or opposition to the change in current flow through it. It tends to smooth

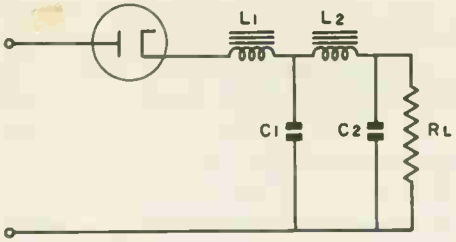

Fig. 19. A two-section choke-input filter.

out the pulses of current through the rectifier tube. The current pulse flowing through the rectifier tube flows for a slightly longer time than it would flow with an equivalent capacitor-input type of filter, and the peak amplitude of the current flowing through the rectifier tube is not as high as it would be with the capacitor input filter. This is a big advantage in a power supply using mercury-vapor rectifier tubes, because they can easily be destroyed by excessively high current pulses through them.

The filter network shown in Fig. 19 is quite effective in eliminating hum. Consider what would happen if the output of the rectifier had an ac voltage of 100 volts superimposed on the dc. If the two sections of the filter network are designed so that each choke has a reactance about 10 times as high as the reactance of the capacitors, each section will have approximately a 10-to-1 ripple voltage division; thus if there are 100 volts ac at the output of the rectifier, L1 and C1 will divide this voltage so that there will be only 10 volts appearing across C1. Now L2 and C2 act as a voltage divider network and divide this 10 volts further, so that the voltage across C2 would be only 1 volt. Thus, the two-section filter has reduced the ac hum or ripple voltage at the rectifier output from 100 volts to 1 volt.

The input filter choke, which is L1 in Fig. 19, is often a swinging choke. A swinging choke is designed so that it saturates rather easily and thus its inductance will vary appreciably as the current through the choke changes. When the current through the choke becomes high, the inductance and hence the inductive reactance of the choke decrease, but when the current through the choke is low, the inductance and hence the inductive reactance increase. Thus we have in effect a variable reactance between the rectifier tube and the input-filter capacitor; this variable reactance helps to improve voltage regulation at the power supply output. This type of choke is particularly useful in circuits where the load current goes through wide variations. If the load current goes down, the reactance of the choke increases. The increased reactance limits the charging action of the rectifier tube and keeps the output voltage from rising appreciably. On the other hand, if the load current increases, the reactance of the choke decreases, allowing the rectifier to charge C1 to a higher value so the capacitor can supply the increased current demand.

FACTORS AFFECTING THE OUTPUT VOLTAGE

In any filter network containing a filter choke or a filter resistor, the dc current flowing through the load must also flow through the filter choke or filter resistor. Thus, there will be a voltage drop across this choke or resistor; the exact value of the voltage drop will depend upon the dc resistance and the current flowing. We already pointed out that if a 1000-ohm filter resistor is used in the circuit and the current that is flowing is 100 milliamperes, the voltage drop across the filter resistor will be 100 volts. On the other hand, if a filter choke having a dc resistance of 100 ohms is used, a current of 100 milliamperes will produce a voltage drop of only 10 volts across it.

If the current drawn by the load changes, the output voltage at the output of the filter network will change. You can see why this is so--the current must flow through the filter resistor or filter choke. If the current flowing through the choke or resistor changes, the voltage drop across it will change, and hence the voltage at the output of the power supply will have some tendency to change.

The output voltage is also affected by the size of the filter capacitors used. If the filter capacitors used are small, then the rectifier is unable to keep them completely charged; if the filter capacitors are large, once the rectifier gets them charged, they will stay charged to a voltage near the peak ac voltage being applied to the rectifier tube.

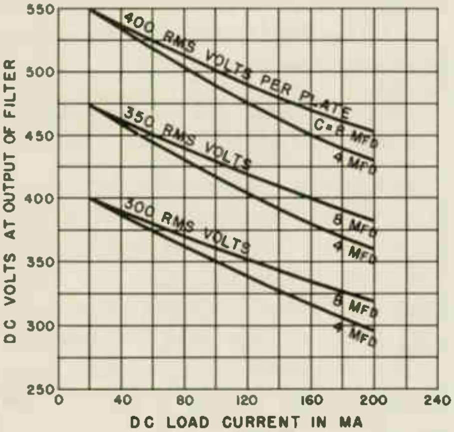

Fig. 20. How the size of the input capacitor of a filter affects the output voltage for different values of load current.

Of course, it is difficult to say whether a filter capacitor is large or small. Whether or not it is large for the particular circuit depends upon how much current is being drawn from the circuit. If the current drain is low, then a capacitor of 10 or 20-mfd will usually be sufficient to keep the power supply output voltage at or near the peak value of the ac voltage applied to the rectifier tube. However, if the current drain from the power supply is large, then the voltage across the power supply output will be considerably less than the peak ac value if the capacitors used are 10-mfd or 20-mfd capacitors.

To give you some idea of how the size of the input filter capacitor affects the output voltage, we have shown a graph in Fig. 20. The graph is for a full-wave rectifier. It shows how the output voltage varies with different load currents for both 4-mfd and 8-mfd capacitors. We have shown this for three separate input voltages. Notice that in each case when the current drain is low, the output voltage is substantially above the rms input voltage applied to the rectifier. Remember, of course, that the peak value of a 300-volt rms voltage is actually 1.4 times 300 volts.

Fig. 21 shows a comparison between a choke-input and capacitor-input type of filter. Notice that with a capacitor input the output voltage at low loads is substantially higher than it is for a choke input. However, as the load is increased, the output voltage from a capacitor-input type of filter drops rapidly. The output voltage from the choke-input type filter also drops as the load is increased, but it does not drop nearly as rapidly as it does with a capacitor-input type of filter.

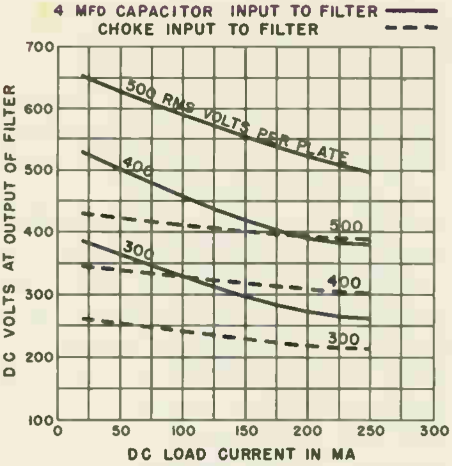

Fig. 21. How the output voltage of a filter network varies for different values of load currents and input voltages. The solid curves are for a capacitor-input filter; the dashed curves for a choke-input filter.

SUMMARY

In this section we have covered some of the more important types of filter networks you are likely to encounter in your career as an electronics technician. You have seen that these networks vary from comparatively simple filters consisting only of a capacitor up to networks containing two chokes and two filter capacitors.

Simpler types of filter networks can be used where the current drain is low and where the filtering does not have to be very good. The more elaborate filters are used in power supplies having a high current drain and in cases where good filtering is required to supply pure dc at the power supply output.

The circuits in this section of the lesson are shown with a half-wave rectifier. The same filter circuits are also used with full-wave rectifiers.

Study the circuits shown in this section. You should be familiar with each of these circuits. You might try drawing these circuits several times to get familiar with the circuit arrangement. Copy them from the book the first few times you try drawing them and then try to reproduce the circuit from memory. This will help you remember what the circuits look like, and if you can remember what they look like, the chances are that you'll be able to remember how they work.

SELF-TEST QUESTIONS

(i) To what value may the input filter capacitor charge in a simple capacitor filter such as shown in Fig. 11?

(j) In what type of application may a simple capacitor-type filter (such as shown in Fig. 11) be used?

(k) What advantage does an R-C pi-type filter (such as shown in Fig. 13) have over the simple capacitor-type filter shown in Fig. 11?

(l) What is the disadvantage of the R-C pi-type filter, and how can this disadvantage be overcome?

(m) What is the purpose of the resistor R1 in the power supply shown in Fig. 17?

(n) Why are choke-input filters used with mercury-vapor rectifier tubes?

(o) What advantage does a choke-input filter have over a capacitor-input filter?

(p) What is a swinging choke?

Typical Power Supplies

The two main sections of the power supply are the rectifier and the filter section. Now that we have discussed both these sections, let's examine some typical power supplies and see what they look like. First we'll look at some power supplies using tube-type rectifiers which might be found in equipment using vacuum tubes. Remember that in these circuits the rectifier operates in the same way as a selenium or silicon rectifier would operate. Insofar as the rectification action is concerned, it makes little difference whether a tube, a selenium rectifier, or a silicon rectifier is used. In the circuits where tubes are used, we will in some cases show how the tube heaters are connected. After looking at a few tube circuits we will look at some typical power supplies using silicon rectifiers and then at a more complex regulated supply.

UNIVERSAL AC-DC POWER SUPPLIES

The universal ac-dc power supply is so called because it can be operated from either an ac or a dc power line. When these power supplies were first used in radio receivers, manufacturers played this feature up, but actually this type of power supply is used to keep costs at a minimum.

The circuit of an ac-dc power supply for a 5-tube radio receiver is shown in Fig. 22. This supply not only supplies the dc voltages required by the plates and screens of the tubes in the receiver but also contains the heater supply for the heaters of the various tubes. First, let us look at the heater supply. Notice that the heaters of the various tubes are connected in series and that they are operated on ac. In this type of power supply you will always find that the heater of the rectifier tube, in this case a 35W4 tube, is connected directly to one side of the power line. The heater of this particular tube is tapped, and a pilot light is connected in parallel with one part of the heater. The pilot light will light when the set is turned on. The tube is designed to be operated with the pilot light connected in parallel with part of the heater, so if in servicing a receiver using a tube with a pilot light tap you should find that the pilot light is burned out, it is a good idea to replace it to keep the heater current in the rectifier tube within its rated value.

Next to the 35W4 rectifier tube in the heater circuit (or heater string, as it is usually called) you will always find the high-voltage power output tube. By a high-voltage tube we mean a tube that requires a high heater voltage. In the diagram we have shown, the tube is a 50B5 tube. As the 50 suggests, a heater voltage of 50 volts is required to operate the tube.

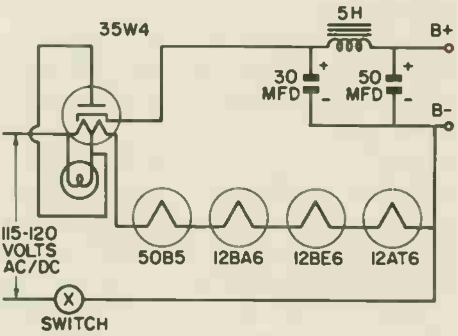

Fig. 22. A typical ac-dc power supply.

Next to the output tube you will usually find the i-f tube. In this diagram, the i-f tube is a 12BA6 tube. It is a tube with a 12.6-volt heater.

Next to the i-f tube you will find the converter tube. The 12BE6 tube is a converter tube designed so that the single tube performs two tasks: one part of the tube is the oscillator and the other part is the mixer.

The last tube in the heater string is always the first audio tube. In this circuit it is a 12AT6 tube. This tube is placed at the end of the heater string nearest B- to keep hum at a minimum, because hum picked up in the first audio tube will be amplified by the entire audio system and could be objectionable. The 12AT6 tube is a dual-diode-triode tube: it has two diodes and a triode inside the same glass envelope. As the 12 preceding the type designation suggests, the tube requires a heater voltage of about 12 volts--to be exact, 12.6 volts.

Now if we examine the rectifier circuit you will see that the plate is connected to a center tap on the rectifier heater. This means that the B supply current flowing through the plate of the tube must flow either through part of the rectifier heater or through the pilot light back to one side of the power line. The purpose of connecting the plate this way is to provide some protection in the event of a short in the receiver. If there is a short in the receiver, the rectifier tube will begin passing excessive current. If this current becomes too high, the pilot light and half the rectifier heater will burn out, opening the circuit and protecting the receiver and the house wiring.

The rest of the power supply is similar to the circuit you studied already. The filter network consists of a capacitor-input filter; the input filter capacitor is the 30-mfd capacitor, and the output filter capacitor is the 50-mfd capacitor. Usually these two capacitors are in a single container that has only three leads brought out from it. Since the negative leads are both connected to B-, a common negative lead and two separate positive leads are usually used. The capacitor is usually a tubular type of capacitor with a paper cover impregnated with wax. The capacitor is mounted on the receiver chassis by means of a mounting strap, or in a receiver with a printed circuit board, the leads are soldered directly to the circuit board. Often this is the only kind of mechanical mounting used.

Capacitors in this type of receiver are usually rated at 150 volts. The normal output voltage of this type of power supply under load is usually somewhere between 90 and 105 volts.

Not all universal ac-dc power supplies use a filter choke. In the circuit shown in Fig. 22, the plates and screens of all of the tubes are operated from the B+ output of this power supply. However, sometimes you will find a filter resistor used in the power supply in place of the filter choke. When this is done, the plate of the output tube is usually connected directly to the cathode of the rectifier tube so that the current drawn by the output tube plate will not flow through the filter resistor. This tube usually draws more current than all the other tubes in the receiver combined.

The output tube is normally a beam tube or a pentode tube, and the plate current depends very little on plate voltage. Therefore if there is some hum voltage applied to the plate of the tube, it usually does not cause any plate current variation and hence is not heard as hum in the output from the loudspeaker. The screen voltage for the output tube and the plate and screen voltages for the remaining tubes are obtained at the output of the power supply where the additional filtering obtained from the filter resistor and the output filter capacitor will reduce the ripple from the rectifier to a low value.

In some of the later table-model radio receivers only four tubes are used; a selenium rectifier or a silicon rectifier is used in place of a rectifier tube because either of these has a considerably longer life. In receivers of this type, tubes with higher heater voltage requirements are often used, so that the sum of the heater voltages required by the four tubes adds up to about 120 volts. If the heater voltage required by the tubes is less than the line voltage, a voltage-dropping resistor can be placed in series with the heaters to use up the leftover voltage. This will cause the total voltage drop across the series-dropping resistor and the tubes to be equal to the line voltage, thus allowing each of the tubes to have its required heater voltage.

Of course, in any heater string where tube heaters are connected in series, all the tubes must have the same heater current rating. Tubes designed for this type of service have what is called a controlled warm-up. This means that the tube heaters are made so that they all reach operating temperature at the same time. This prevents one tube from warming up too quickly and from having too high a voltage across its heater.

The voltage across the tube heater will depend upon its resistance, which changes with temperature. As long as all the tubes warm up at the same rate, their resistances change at the same rate. In this way, a high voltage across any of the tubes is avoided.

Before leaving our study of this type of power supply, it is worthwhile to consider what will happen if a tube such as the 12BA6 tube in Fig. 22 develops a cathode-to-heater shortage. The cathode will usually be connected either to B- directly or to B- through a low-value resistor; this will effectively short out the heaters of the 12BE6 and 12AT6 tubes and, as a result, these tubes will not light.

If you're called upon to service a receiver of this type and you find that one or more of the tubes is not heating, look for a cathode-to-heater short in either the tube which doesn't light that is highest up on the string, or the tube preceding it. If none of the tubes lights this is an indication, since the tubes are connected in series, that the series string is open -- chances are that the heater of one of the tubes has burned out.

A TYPICAL FULL-WAVE POWER SUPPLY

Fig. 23 illustrates a typical power supply using a power transformer and full-wave rectifier. This type is found in many radio and TV receivers and transmitting equipment, as well as in the equipment used in industrial electronics.

Notice that the power transformer has a primary winding to which the 115-volt ac power line is connected; a high-voltage secondary with its center tap grounded, and the two end leads connected to the plates of the rectifier tube; and the two filament

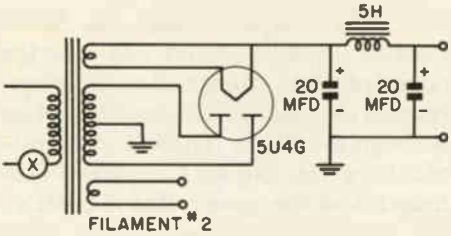

Fig. 23. A typical power supply using a transformer and full-wave rectifier.

windings. One filament winding is used to supply the heater voltage required by the rectifier tube, and one filament winding is used to supply the heater voltage for all the other tubes in the set.

In this power supply we have shown a 5U4G rectifier tube, which requires a heater voltage of 5 volts and a heater current of 3 amps. Thus the rectifier filament winding on the transformer must be capable of supplying 5 volts at a current of 3 amperes.

The winding marked filament number two is used to supply the heater voltage required by all the other tubes in the set. You will notice that this winding is called the filament winding, not the heater winding. This is a carry-over from the old days of radio when most of the tubes were filament-type tubes and few had a separate cathode and heater.

In an electronic device using this type of power supply, the heaters of the tubes (with the exception of the rectifier tube) are connected in parallel. Since the tubes are connected in parallel, you will find that all of the tubes are designed to operate from the same heater voltage. In most cases equipment using this type of power supply has tubes with heater voltage ratings of 6.3 volts. The filament winding must be capable of supplying the heater current required by all of the tubes. The tubes may require different heater currents since they are connected in parallel. You can determine the total current the winding must supply by looking up the heater current required by the individual tubes in a tube manual and adding these figures together.

Again, the filter network used in this power supply is a capacitor-input type. Notice that the capacitors have a lower capacity than those used in the circuit shown in Fig. 22. It is not as necessary to use large capacitors in a full-wave rectifier type of power supply as it is in a half-wave rectifier to obtain the same amount of filtering. Of course, in some power supplies in which it is essential to keep the hum voltage very low, you will find larger filter capacitors. You may also find a two-section filter using an additional choke and a third filter capacitor.

In a power supply such as the one shown in Fig. 23, the two capacitors will probably be mounted in a single container. If a cardboard tubular type is used, one common negative lead and two separate positive leads will be brought out of the container. The same color leads will probably be used for the two positive sections since they both have the same capacity. In some pieces of equipment a metal can-type capacitor might be used -- with this type the can is usually the negative terminal. Mounting the capacitor on the metal chassis automatically makes the connection between the negative terminal and the chassis. The positive leads are brought out of two separate terminals.

DUAL-VOLTAGE POWER SUPPLIES

A diagram of a typical dual-voltage power supply is shown in Fig. 24. This diagram is actually quite similar to the diagram of circuits used in a modern color-TV receiver. Notice that a voltage that is negative with respect to ground is developed by the diode D1 and its associated circuitry. Diodes D2 and D3 are used in a half-wave voltage doubler circuit.

In this circuit when terminal A is negative with respect to terminal B, current flows from A through R1 and D1 to charge capacitor C1. A simple pi-type R-C filter is used in this section of the power supply because the current requirements are low and there will be very little voltage drop across R2. At the same time with the two capacitors, small value capacitors can be used and adequate filtering obtained.

When terminal A is negative, current also flows through the thermistor R3 through R4 and into the negative plate of capacitor C3. Electrons flow out of the positive plate through the diode D2 back to terminal B of the power line. When terminal A of the power line is positive and terminal B is negative the voltage will be placed in series with the voltage built up across C3, so that capacitor C4 is charged to a value approaching twice the peak line voltage through diode D3. This provides an output voltage which is positive with respect to ground and approximately equal to twice the ac line voltage.

The thermistor R3 is put in the circuit to prevent high current surges through the silicon diodes D2 and D3 when the equipment is first turned on. R4 is used in the circuit to provide further protection. If the equipment is turned on and operating for some time, the resistance of the thermistor will drop to a low value. If the equipment is turned off for a

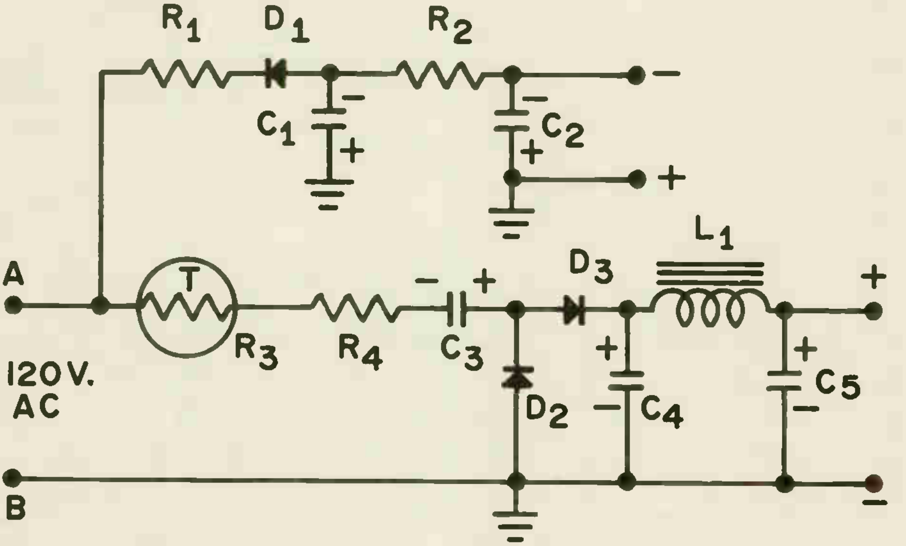

Fig. 24. A typical dual-voltage power supply.

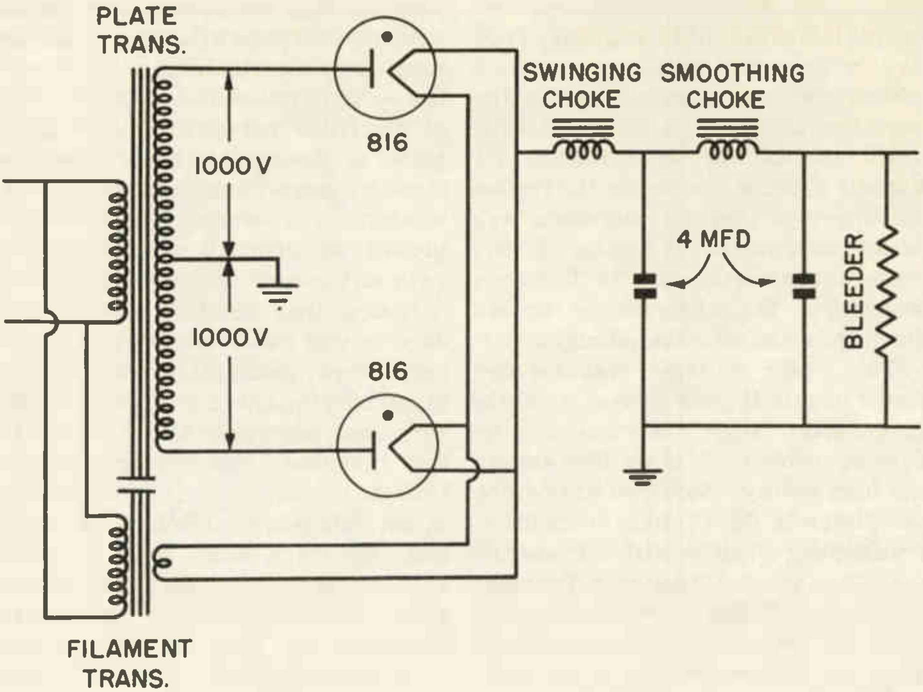

Fig. 25. A typical transmitter power supply.

few seconds and then turned back on, the charging current through the diodes could be quite high and damage them. R4 is put in the circuit; its value does not change and it limits the current through the diodes to prevent their damage under this circumstance.

The power supply shown in Fig. 24 is typical of the power supply you are likely to run into in both monochrome and color television receivers. A voltage-divider network may be used across the output of either supply to provide different value voltages. This power supply is comparatively inexpensive; it eliminates the need of a power transformer and with modern silicon diodes is comparatively trouble-free.

HIGH-VOLTAGE POWER SUPPLIES

Another power supply is shown in Fig. 25. This is the type of power supply you will find in transmitting equipment or in other equipment where high operating voltages are required. Notice that in this power supply, full-wave rectification is used. Also notice that it has two separate rectifier tubes. Separate rectifier tubes rather than a single tube with two plates are used in high-voltage supplies because the voltages are so high that they would simply arc across inside the tube. The type 816 tubes shown in this supply are mercury-vapor tubes designed for use in power supplies where the operating voltages are not too high and where the current requirements are not too great. They are often used in power supplies where the ac input voltage to the rectifier is between 1000 and 2000 volts, and the current drain does not exceed 250 ma. As far as the transmitting-type power supplies are concerned, an output voltage of 1000 volts across each half of the secondary of the high-voltage transformer is not considered high.

The high-voltage transformer found in this type of power supply is frequently called a plate transformer because it is used to supply the high voltage required to operate the plates of the various tubes in the transmitter. The rectifier tubes are operated from a separate filament transformer. In a power supply using type 816 tubes, the filament voltage required by these tubes is 2.5 volts and the current required is 2 amps. Therefore, this filament transformer must be capable of supplying a total of 4 amps at a voltage of 2.5 volts. The filament transformer must have good insulation between the secondary winding, the transformer core, and the primary winding; otherwise the high voltage will arc through the insulation either to the primary winding or to the transformer core.

At the input of the power supply filter network is a swinging choke. This is common practice in transmitter power supplies because it improves the voltage regulation, and also because it affords additional protection for the mercury-vapor rectifier tubes.

The second choke in the power supply is called a smoothing choke. This is the same type of choke shown in the power supplies in Figs. 22 and 23. It is called a smoothing choke in transmitting equipment because its primary purpose is to smooth out the ripple and also to distinguish it from the swinging choke used at the input of the filter network. A smoothing choke is designed to keep its inductance as nearly constant as possible, whereas a swinging choke is designed so that its inductance will vary as the current through it varies.

Notice that the filter capacitors used in this power supply are 4-mfd capacitors. Each of these capacitors is usually mounted in its own separate container. Occasionally you will find two small high-voltage capacitors in the same container, but this is not common practice. Also notice that the capacitors have a much smaller capacity than those in the two power supplies we discussed previously. These capacitors are oil-filled capacitors and it is quite costly to make this type of capacitor with a large capacity. On the other hand, capacitors used in circuits like those in Fig. 22, Fig. 23, and Fig. 24 are electrolytic capacitors and very large capacities can be obtained at a very moderate cost.

Effective filtering is obtained with the smaller-size capacitors in this supply, because two filter chokes are used. The inductance and hence the inductive reactance of these chokes are usually somewhat higher than that of filter chokes used in lower voltage equipment. The choice of using either large chokes or large filter capacitors is simply one of cost. At low voltages it is more economical to use large capacitors and low-inductance chokes, but at high voltages it is more economical to use high-inductance chokes and low capacities. The net result is the same as far as the filtering action is concerned. Another component that you will find in transmitting-type power supplies is a bleeder. A bleeder is a resistor connected across the power supply output. The bleeder serves two purposes: it improves the voltage regulation and is also used for safety.

A bleeder resistor connected across the power supply keeps the minimum current at a reasonable value. If the current drawn by the load connected to this power supply were to drop to zero, the two filter capacitors would be charged up to a value equal to the peak voltage across half of the secondary of the plate transformer. If the transformer had an rms voltage of 1000 volts across each half of the secondary, this would mean that the capacitors would charge up to a voltage of about 1400 volts. This may be high enough to destroy the capacitors. Also, the chokes have a definite maximum voltage that can be applied to them. If the voltage goes too high, the insulation between the choke winding and the core may break down. This will destroy the chokes. If either of the chokes or capacitors shorts, the rectifier tubes will pass such a high current that they may be ruined. There is also the danger of burning out the plate transformer. Furthermore, if the voltage reaches too high a value, the rectifier tubes may arc over internally. A bleeder connected across the power supply output can eliminate this danger. With the bleeder across the output, if the equipment current drops to or almost to zero, the bleeder current will continue to flow. If the output voltage starts to rise, the bleeder current will increase because the current flowing through any resistor increases if the voltage across it increases. The bleeder current will keep the voltage from climbing to an unsafe value.

Another important reason for using the bleeder is that an oil-filled capacitor such as those found in this type of power supply can hold a charge for a long time. If the two 4-mfd capacitors used in the supply were charged up to a voltage of 1000 volts or more and a technician servicing the equipment accidentally touched one of these capacitors, he could receive a very dangerous shock. Under certain conditions it could be fatal. This danger can be greatly reduced by connecting a bleeder across the power supply so that when the equipment is turned off the capacitors are discharged through the bleeder.

You may have occasion to work on high-voltage power supplies at some future date. Remember that a bleeder is connected across the power supply for safety as well as to improve the voltage regulation. Therefore if the bleeder in a power supply burns out, it should be replaced. However, never rely on a bleeder to discharge high-voltage filter capacitors. If you have to work on a high-voltage power supply, your first step should be to remove all voltages from the supply. To do this, turn the power supply off; if there are fuses in it, remove the fuses so that no one can accidentally turn it on; disconnect it completely from the source if you can. Often it is not possible or convenient to completely disconnect the equipment from the voltage source but if it is shut off and any fuse in the circuit is removed, it should be safe. Next, before you start to work on the supply, discharge all filter capacitors in the power supply. The capacitors should be discharged with a heavy metal rod that has a good insulated handle so that you will not come in contact with the metal rod. Use the metal rod to short together the terminals of the capacitor to discharge it. Touch the grounded terminal of the capacitor first and slide the rod over to touch the other terminal. Do this several times to be sure the charge is completely removed. After the capacitors have been discharged, the power supply should be safe to work on.

Keep this point in mind: high voltage capacitors, or for that matter any large capacitors, should be discharged before you start to work on a piece of equipment. Many technicians fail to do this. There are some technicians who can tell about the terrific shock they received when they failed to discharge a filter capacitor. There are others that did not survive the experience to tell about it.

A TRANSISTOR-REGULATED POWER SUPPLY

A regulated power supply employing transistor voltage regulators is shown in Fig. 26. This power supply is used in a TV receiver that is designed for operation from the power line and also from a 12-volt dc source. When the power plug is plugged into a 120-volt line and the switch is turned on, the receiver will operate from the power line. When the power plug is disconnected and switch S1 is closed, the receiver can be operated from a 12-volt battery.

The operation of the power supply from the power line is comparatively simple. Two diodes, D1 and D2, are used in a full-wave rectifier circuit. When the transformer T1, which is a step-down transformer, has a polarity such that the end of the secondary connected to D1 is negative, current will flow through the diode D1 to ground and into the negative plate of C3. Electrons flow out of the positive plate of C3 to the center tap of the power transformer which is positive with respect to the end connected to D1. During the next half-cycle, when the end of the secondary connected to D2 is negative, current will flow through D2 to ground, into the negative plate of C3,

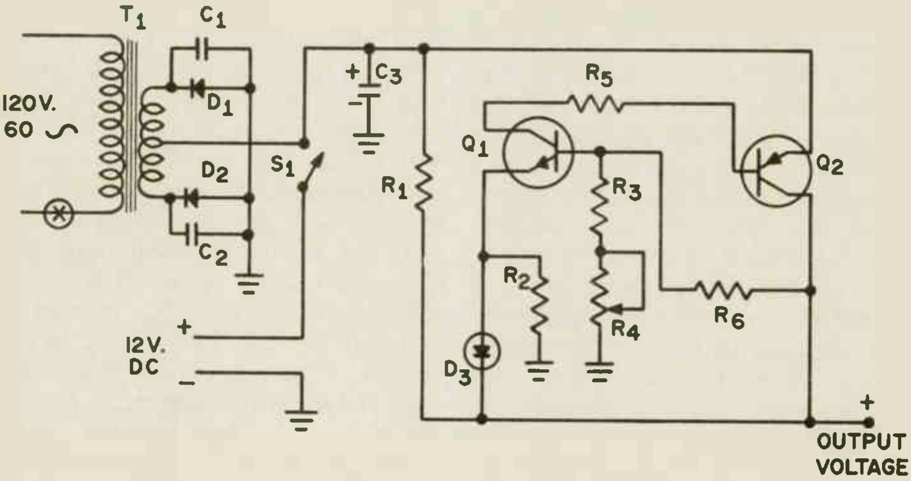

Fig. 26. A transistor-regulated power supply.

out of the positive plate of C3 and back to the center tap of the secondary winding on the power transformer.

The remainder of the components used for the power supply are used for the purpose of regulating the voltage. In other words, the power supply voltage is maintained constant at approximately 12 volts regardless of the load drawn from the supply. The transistor Q2 is a PNP transistor that is used as a series voltage regulator. Notice that the emitter of this transistor connects directly to the positive side of C3. You can consider this transistor as working more or less as a variable resistor: if the output voltage tends to rise, the resistance increases and if the voltage tends to fall, the resistance decreases.

The effective resistance of Q2 is varied by varying the forward bias across the emitter-base junction. Notice the zener diode D3. This diode is connected in series with R2. The zener has a constant voltage of 6.3 volts across it. Therefore, the voltage drop across R2 will be equal to the output voltage minus 6.3 volts. This is the emitter voltage applied to Q1. The base voltage is determined by the voltage division occurring between R4, R3 and R6. R4 is adjustable so that the output voltage can be adjusted to 12 volts. Under these circumstances a certain current will flow through Q1 and through R5 and this will set the forward bias on Q2. If the output voltage tends to rise, the base voltage on Q1 will rise but by an amount less than the emitter voltage. The divider network consisting of R4, R3 and R6 will prevent the base from rising the full amount of the output voltage rise. On the other hand, the voltage across the zener D3 remains constant so that the voltage across R2 will reflect the entire output voltage rise. This will reduce the forward bias on Q1 which, in turn, will reduce the emitter-collector current. The reduction in the emitter-collector current will reduce the voltage drop across R5 which, in turn, will reduce the forward bias on Q2; this has the effect of increasing its resistance. The increased resistance tends to keep the output voltage from increasing.

If the output voltage decreases, the opposite happens. The base voltage on Q1 falls, as does the emitter voltage. However, the emitter voltage falls more than the base voltage, so the forward bias is increased. This increases the emitter-to-collector current through Q1 which increases the forward bias on Q2. This has the effect of reducing the resistance on Q2 and tends to keep the output voltage from falling.

This type of power supply is one of the more complex power supplies that you are likely to encounter in electronic equipment. The voltage regulation is required in order to keep the voltage reasonably constant on the various transistors used on the TV receiver. In most cases, such precise voltage regulation is not required in entertainment-type equipment.

VOLTAGE DIVIDERS

We mentioned previously that more than one operating voltage is sometimes needed in the various stages of a piece of electronic equipment. Rather than use a separate supply for each voltage needed, the usual procedure is to use a single supply designed to give the highest voltage needed, and then obtain the lower voltages required by means of a voltage divider connected across the power supply output. A typical voltage divider is shown in Fig. 27.

In this voltage divider, R1 and R2 are voltage-dropping resistors; they drop the voltage from 300 volts to the required voltages of 200 and 100 volts. R3 is a bleeder used to stabilize the voltages at points B and C. With this type of network, terminal D is the ground or common terminal. Between D and C there is a voltage of 100 volts; terminal C is positive with respect to terminal D. Between D and B there is a voltage of 200 volts and terminal B is positive with respect to terminal D. Finally, between terminals D and A there is the full power supply output voltage of 300 volts, and of course terminal A is positive with respect to terminal D.

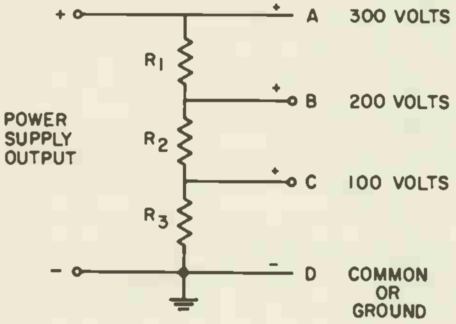

Fig. 27. A voltage-divider network.

The current flowing through R3 is called the bleeder current. It remains fairly constant and is determined primarily by the sizes of R1, R2 and R3. Usually, the size of R3 is chosen so that the bleeder current will be at least as great as the current drawn by the stages connected to terminals C and B. Choosing a value of R3 that will result in a reasonable bleeder current helps maintain good voltage regulation at terminals C and B.

The current flowing through R2 will be made up of the bleeder current plus the current drawn by the stages connected to terminal C. If this current varies, the voltage drop across R2 and hence the voltage at terminal C will vary. However, the bleeder current will remain essentially constant so that if a sizable percentage of the current flowing through R2 is bleeder current, variations in the current drawn by the stages connected to terminal C do not cause too much variation in the voltage drop across R2.

The current flowing through R1 is made up of the bleeder current plus the current drawn by the stages connected to terminals C and B. Again if the bleeder current through R1 represents a sizable part of the total current flow through R1, variations in the current drawn by the stages connected to terminals C and B do not cause too great a variation in the voltage drop across R1 so the voltage at terminal B will remain reasonably constant.

Bleeders are not used in modern midget radio receivers, but you will find them in many of the older sets. They are frequently used in TV receivers, in the low-voltage power supplies in transmitting equipment, and in industrial electronic equipment.

Sometimes one section of a tapped resistor will burn out. Often you can repair the equipment simply by connecting a resistor having the correct resistance and a suitable wattage rating across the defective section. Of course, if separate resistors are used in the voltage divider you can simply replace any defective one. If you do shunt a burned out section of a tapped resistor in a radio receiver and find the equipment is noisy after you have made this repair, the defective section may be making contact intermittently and creating the noise. Of course in this case you must replace the entire unit either with separate resistors connected in series or with a tapped resistor like the original one.

VIBRATOR-TYPE SUPPLIES

The radios installed in automobiles for years used a power supply known as a vibrator type of power supply. A schematic diagram of this type of power supply is shown in Fig. 28. The heart of this type of power supply is the vibrator, which is used to change the dc from the automobile storage battery to a pulsating current in the primary winding of the power transformer.

The vibrator consists of an electromagnet L, and a reed (R-K) placed between two sets of contacts. In the circuit shown in Fig. 28, when the switch is turned to the ON position, current will flow from the negative terminal of the battery through the switch and through the reed towards terminal M. Here it will flow from the reed to contact M, to coil L, through coil L back to the positive side of the battery. The current flowing through the coil creates a magnetic field. This magnetic field attracts the end of the reed K, pulling the reed over toward L and contact N. When the reed makes contact with terminal N, current flows through the upper half of the transformer primary winding. It flows from the top of the winding to the center tap, building up a magnetic field.

At the same instant that the reed is making its contact with terminal N, it will break its contact with terminal M so that the electromagnet will no longer be energized and the field about it will collapse. The reed is made of a spring type material so that it springs back until it makes contact with both terminal M and terminal O. At the instant contact is made with terminal O, current flows through the lower half of the primary winding of the transformer, flowing from the bottom of the winding towards the center tap. The current is flowing through the primary winding in the opposite direction to the direction in which it was flowing through the upper half of the trans-

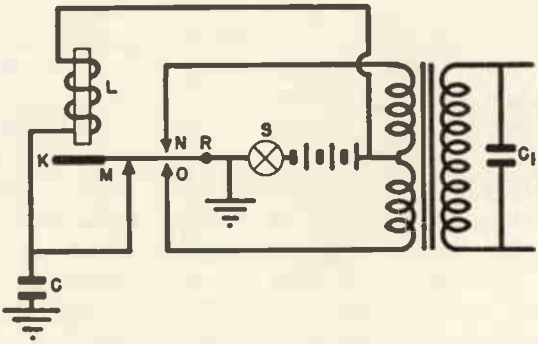

Fig. 28. A vibrator circuit.

former winding. Thus we have a field built up in one direction and then in the opposite direction. At the same time the fact that the reed makes contact with terminal M will once again complete the circuit through the electromagnet so the reed will swing over to the magnet again, making contact with terminal N. As you can see this action causes the reed to vibrate back and forth between terminals N and O. Thus we have a field built up in the primary first in one direction and then in the opposite direction. Building up this field, collapsing it, and then building up a reverse field and collapsing it, means that we have a continually changing magnetic field cutting the secondary of the transformer. By putting a large enough number of turns on the secondary, we can obtain whatever voltage we may require for the operation of the receiver.

A complete vibrator-type power supply is shown in Fig. 29. Notice that the secondary of the vibrator transformer is center tapped and that a full-wave rectifier is used. The capacitor C_2 is called a buffer capacitor. This is a high voltage paper capacitor that is used to keep sharp noise pulses out of the power supply. The size is usually quite critical and if it is necessary to replace the buffer capacitor in a receiver using this type of power supply, you should use a capacitor having the same capacity as the original.

In a vibrator-type power supply there is considerable sparking as the reed vibrates back and forth. This sets up a radio-frequency type of interference which could get through the rectifier and cause considerable interference in the receiver. In the power supply shown in Fig. 29, the choke L and the capacitor C are called hash suppressors. This rf interference or noise is called hash; the choke and the capacitor are put in the power supply in order to keep as much as possible of this hash or noise out of the power supply output. Capacitor C acts like a short circuit to these radio frequency pulses, and choke L acts like a very high impedance to them. Thus L and C form a voltage-divider network, with most of the voltage appearing across the high impedance L and little or no voltage across the low impedance C.

Vibrator-type power supplies were used in almost all automobile receivers in automobiles using 6-volt ignition systems. However, in newer cars, a 12-volt ignition system is used. The first receivers made for these cars also used vibrator type supplies, but tube manufacturers designed special tubes that will operate with plate and screen voltages as low as 12 volts. These 12-volt tubes were used in automobile receivers for a few years, but they too were replaced by transistors. Since transistors operate from low voltages, the vibrator type of power supply is no longer needed. These supplies were not only costly, but in addition they were one of the most troublesome sections of the automobile receiver.

SUMMARY

The power supplies we have shown in this section of this lesson are typical of the various types of power supplies you are likely to encounter as an electronics technician. You will find many variations of these circuits, but these are the basic circuits. Spend some time studying

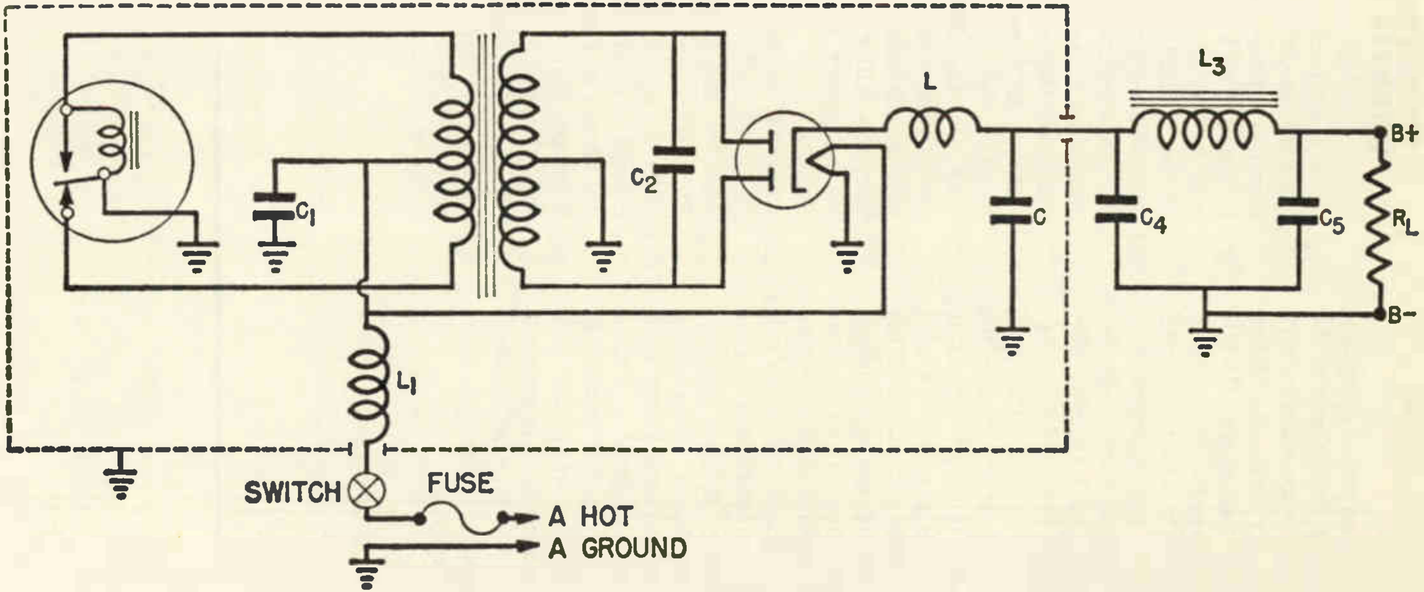

Fig. 29. A complete vibrator power supply.

these circuits so you will know what they look like.

In servicing these power supplies, keep in mind that the values of the various components used are generally not extremely critical. Manufacturers usually use as small a filter capacitor as they can in a circuit. It is more economical to use a small capacitor than to use a large one. Therefore, if you have an ac-dc receiver that uses a 20-40 mfd, 150-volt capacitor and you find it necessary to replace the filter capacitor, there is no reason why you could not use a 30-50 mfd, 150-volt capacitor in its place. Some variation of part values can be made without affecting the performance of the equipment.

It is also possible to use capacitors having a higher voltage rating than those used originally. This will simply provide an additional margin of safety. You may find that you cannot do this in large transmitter power supplies because there isn't room to mount a capacitor with a higher voltage rating, but usually in radio, TV, and most small pieces of industrial electronic equipment there is enough room to put in a capacitor of slightly larger physical size than the original.

SELF-TEST QUESTIONS

(q) Draw a schematic diagram of a typical ac-dc power supply found in a five-tube radio.

(r) In the circuit shown in Fig. 22, why is the 12AT6 tube placed at the B- end of the string?

(s) If in an ac-dc receiver in which the heaters of the tubes are connected in series and none of the tubes lights what would you suspect the cause of the trouble to be?

(t) Why are the filter capacitors used in the power supply shown in Fig. 23 smaller in capacity than the filter capacitors used in the power supply shown in Fig. 22?

(u) What is the purpose of R3 in Fig. 24?

(v) What is the purpose of R4 in Fig. 24?

(w) What type of voltage-doubler circuit is used in the power supply shown in Fig. 24?

(x) What purpose does the transistor Q2 serve in the power supply shown in Fig. 26?

(y) What is the purpose of the diode D3 in Fig. 26?

ANSWERS TO SELF-TEST QUESTIONS

(a) There will be 60 current pulses per second through the load.

(b) The disadvantage of the half-wave rectifier circuit is that current flows through the rectifier during one half-cycle and not during the other half-cycle. As a result, the output is somewhat difficult to filter and smooth out to pure dc.

(c) The diode D1 in the circuit shown in Fig. 6 is used to charge the capacitor C1 during one half of each cycle. Capacitor C1 is charged so that during the next half-cycle the voltage across it will be in series with the line voltage. This will place a voltage equal to twice the line voltage across the load and diode D2. Since diode D2 has a very low resistance when it is conducting, the voltage across the load is twice what it would be without the combination of C1 and D1 in the circuit: hence, the circuit is called a voltage-doubler circuit.

(d) The circuit is called a full-wave rectifier circuit because a current pulse flows through the load during each half-cycle. In other words, if the rectifier circuit is operating from a 60-cycle power line there will be 120 current pulses through the load (one for each half-cycle).

(e) The disadvantage of this circuit is that the high voltage winding on the power transformer must be center-tapped. This means that the high-voltage winding on the transformer must have twice the number of turns required to get the desired output voltage across the load. This circuit requires a rather expensive power transformer.

(f) The advantage of the bridge rectifier circuit is that there is a saving in the power transformer cost over that of a transformer that has a tapped high-voltage secondary winding; also, the circuit is capable of good voltage regulation.

(g) The voltage-doubler circuit shown in Fig. 9 is a full-wave voltage doubler. That is, there will be 120 current pulses per second in the output of the voltage doubling capacitor network consisting of C1 and C2. The circuit shown in Fig. 6 is a half-wave voltage-doubler circuit and there will be only 60 current pulses through the load in this circuit. It will be somewhat easier to filter and smooth the output voltage in the circuit shown in Fig. 9 than it will be in the circuit shown in Fig. 6.

(h) A full-wave doubler circuit requires a less expensive power transformer for a given load voltage than the bridge rectifier circuit requires. Also, the voltage-doubler circuit requires only two rectifiers whereas the bridge-rectifier circuit requires four rectifiers. The disadvantage of the full-wave voltage-doubler circuit is that it does not have as good voltage regulation as the bridge-rectifier circuit.

(i) The capacitor in a simple filter circuit such as shown in Fig. 11 may charge up to a value equal to the peak value of the ac input voltage. In the case of a power supply operating from a 120-volt line this is equal to approximately 1.4 times 120 volts.

(j) A simple capacitor-type filter may be used in applications where the current drain is low. With a low current drain the capacitor discharges very little between cycles so that the voltage across the capacitor, and hence the voltage across the load, remains essentially constant.

(k) The R-C pi-type filter is capable of better hum elimination than a simple capacitor-type filter. This type of filter is particularly desirable where the current drain is high enough to discharge the capacitor appreciably between charging cycles in a simple capacitor-type filter.

(l) The disadvantage of the R-C pi-type filter is that there is considerable voltage drop across the filter resistor. This problem can be overcome by using a filter choke such as in the L-C type filter shown in Fig. 15. A filter choke will offer a high opposition to any ac and thus effectively reduce the ac, while at the same time offering a low resistance to the passage of dc through it.

(m) R1 in the power supply shown in Fig. 17 is used to limit the current through the silicon rectifier when the power supply is first turned on. Without this resistance in the circuit, the charging current through the diode to charge C1 may be so high that the rectifier may be destroyed.

(n) To limit the peak current through the tubes. A mercury vapor rectifier tube is easily damaged by a high peak current. The peak current through the rectifier tube is much lower with a choke-input filter than it is with a capacitor-input filter.

(o) A choke-input filter will provide better regulation than a capacitor-input filter. This means that the voltage across the load will vary less with widely varying currents when the filter is a choke-input filter than it will when the filter is a capacitor-input filter.

(p) A swinging choke is a choke whose inductance changes as the current changes. As the current builds up the choke tends to saturate so that its inductance goes down. This tends to reduce the reactance of the choke and hence helps provide better voltage regulation.

(q) See Fig. 22. If you cannot draw this diagram from memory, copy it from the book. Simply drawing the diagram will help you to become familiar with the circuit and remember it in the future.

(r) The 12AT6 tube is the first audio stage. It is placed at the B- end of the heater string in order to keep hum pick-up in the tube as low as possible. Any hum picked up by this tube will be amplified by the entire audio system.

(s) The chances are that the heater of one of the tubes is open.

(t) The power supply shown in Fig. 23 uses a full-wave rectifier. Therefore there will be 120 pulses per second to charge the filter capacitors. The power supply shown in Fig. 22 is a half-wave power supply and there will be only 60 pulses per second to charge the filter capacitor; therefore, larger capacitors are needed to eliminate hum.

(u) R3 in Fig. 24 is a thermistor. A thermistor has a high cold resistance, but the resistance decreases as the thermistor heats up. The thermistor is used in this power supply to protect the diode rectifiers from high current surges when the power supply is first turned on.

(v) R4 is a fixed resistor that is used to protect the diodes in the event the equipment is turned off and then turned back on almost immediately. Under these conditions the resistance of the thermistor will be too low to provide the required protection for the rectifiers and hence R4, along with the hot resistance of the thermistor, limits the current through the diode rectifiers to a safe value.

(w) A half-wave voltage doubler.

(x) Q2 is in series with the B supply voltage. It operates essentially as a variable resistor and is used to regulate the power supply output voltage and keep it at essentially a constant value.

(y) The diode D3 is the zener diode. It provides a reference voltage so that the voltage variations on the emitter of Q1 will be greater than the voltage variations on the base. Thus, changes in output voltage affect the forward bias of the transistor and hence the conduction through it.

Lesson Questions

Be sure to number your Answer Sheet B201.

Place your Student Number on every Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time, or you may run out of lessons before new ones can reach you.

1. What advantage does a silicon rectifier have over a vacuum-tube rectifier?

2. Draw the schematic symbol for a silicon rectifier, and indicate by an arrow the direction in which the current will flow through it.

3. How many pulses per second will you get at the output of a full-wave rectifier that is operated from a 60-cycle power line?

4. What is the purpose of C1 and D1 in the circuit shown in Fig. 6?

5. (a) In the circuit shown in Fig. 6, how many current pulses will there be through the load (60-cycle power line)?
   (b) In the circuit shown in Fig. 9, how many current pulses will there be through the load (60-cycle power line)?

6. In the circuits shown in Fig. 11, what part supplies current to the load when the rectifier is not conducting?

7. Explain the following things in connection with the L-C circuit shown in Fig. 15:
   (a) The action of the choke when ac flows through it.
   (b) The action of the choke when dc flows through it.
   (c) The action of the capacitor when ac flows through it.
   (d) The action of the capacitor when dc flows through it.

8. What type of filter network has better voltage regulation -- the capacitor input or the choke input?

9. If you are servicing a five-tube table model radio that uses a universal ac-dc power supply and you see that two of the tubes are not lighting, where would you look for trouble?

10. How does an increase in output voltage affect Q1 and Q2 in the regulated power supply shown in Fig. 26?

HOW TO START STUDYING

For some people, starting to study is just as hard as getting up in the morning. An alarm clock will work in both cases, so try setting the alarm for a definite study-starting time each day. Start studying promptly and definitely, without sharpening pencils, trimming fingernails or wasting time in other ways.

Beginning is for many people the hardest part of any job they tackle. So formidable does each task appear before starting that they waste the day in dilly-dallying, in day-dreaming, and in wishing they didn't have to do it. The next day and the next after that are the same story. Indecision brings its own delays, making it harder and harder to buckle down to work.

Are you in earnest? Then seize this very minute; begin what you can do or dream you can. Boldness in starting a new lesson is a great moral aid to mastery of that lesson; only begin, and your mind grows alert, eager to keep on working. Begin, and surprisingly soon you will be finished.

J. M. Smith


nri

ACHIEVEMENT THROUGH ELECTRONICS

LOW-FREQUENCY VOLTAGE AND POWER AMPLIFIERS

B202

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LOW-FREQUENCY VOLTAGE AND POWER AMPLIFIERS

B202

STUDY SCHEDULE

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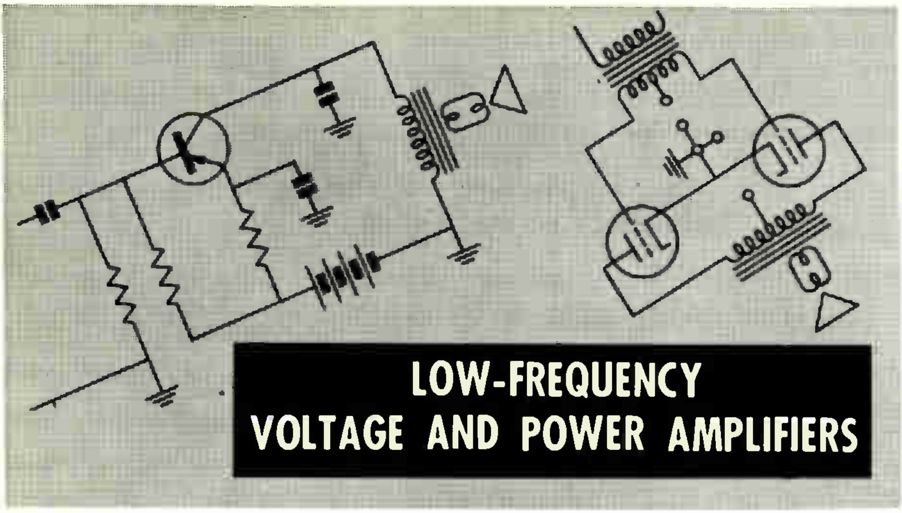

LOW-FREQUENCY VOLTAGE AND POWER AMPLIFIERS

In this lesson and the next two, we will take up the study of amplifiers. For convenience in studying them, we have divided them according to the frequencies they are designed to handle.

You will study low-frequency voltage and power amplifiers in this lesson. These are the kinds used to amplify the sound or audio signal in radio and television receivers, and they are also used in high-fidelity and stereo equipment, in conjunction with amplifying audio signals that are received by means of a radio system from a broadcast station and also with audio signals from a phonograph or tape recorder.

In your next lesson you will study radio frequency amplifiers. These amplifiers are designed to amplify signals received directly from radio and television stations as well as signals within the receiving equipment itself that fall within the radio frequency range. You will study wide-band amplifiers in the third lesson; these are amplifiers that are designed to amplify a wide range of frequencies. For example, a wide-band amplifier might have to amplify signals that have few cycles per second, signals as high as several megacycles per second, and all the frequencies in between these two limits. Wide-band amplifiers of this type are used to amplify the picture signals in television receivers. They are also used in many other special applications.

The ability of tubes and transistors to amplify signals is essentially what makes many of our modern electronic devices possible. Therefore, if you understand how these amplifiers work and how they are put together to perform specific functions, you will be able to analyze the operation of many different types of electronic equipment that you might encounter. Since amplifiers are so important it is worthwhile to spend as much time as necessary on this lesson and on the next two to be sure that you have a complete understanding of them.

The low-frequency amplifiers that you will study in this lesson can be divided into two types: voltage amplifiers and power amplifiers. As you already know, a voltage amplifier is one that is designed to amplify a weak signal voltage and make it stronger. For example, the output voltage from a phonograph pickup in a record player might be only a few thousandths of a volt. This audio signal is too weak to do anything with directly so we feed it to a number of voltage amplifiers to build the amplitude of the voltage up to a usable value. We try to perform this amplification without changing the signal in any way. If we change the signal, we have introduced something called distortion because the amplified signal is no longer the amplified equivalent of the original signal.

Power amplifiers are used to drive the speaker in radio and TV receivers. The speaker requires a certain amount of power in order to cause the cone in the speaker to vibrate back and forth and set the air in front and in back of the speaker into motion. The power required to perform this function is supplied by power amplifiers. The exact amount of power required for the speaker will depend upon the design of the speaker, its size, efficiency and a number of other factors. You will study amplifiers that have a comparatively low power output of perhaps one or two watts and you will also study high-power amplifiers that are capable of putting out 50 or more watts of power.

When we speak of low-frequency amplifiers, we are generally concerned with amplifiers that are designed to amplify signals from about 50 to 100 cycles up to signals of about 10,000 or 20,000 cycles. There are no sharp dividing lines either at the low-frequency or high-frequency end of the range over which the amplifiers are supposed to work. Generally, a low-frequency amplifier is an amplifier that works in the audio range (in other words, within the limits of our hearing). Of course, these amplifiers will amplify signals beyond these frequency limits. The amplifier does not simply stop amplifying at a frequency above the highest frequency it is designed to amplify -- it just doesn't amplify higher frequency signals well. The same is true of low-frequency signals. If an amplifier is designed to amplify signals from about 100 cycles up, it will also amplify a signal having a frequency of 80 cycles, but the chances are that the 80-cycle signal will not receive as much amplification as the 100-cycle signal would.

In this lesson you will learn why the gain of an amplifier falls off as the frequency of the applied signal falls above or below the frequency limits of the amplifier. You will also see that the frequency limits of the amplifier are more or less arbitrarily fixed by design engineers.

In our study of low-frequency amplifiers we will begin with voltage amplifiers. We will study the resistance-capacitance coupled voltage amplifier first because it is the most widely used and hence the most important.

Resistance-Capacitance Coupled Voltage Amplifiers

Resistance-capacitance coupling, usually called R-C coupling or simply resistance coupling, is so named because resistors and capacitors are used to couple the signal from one stage to another.

This type of coupling is widely used between voltage amplifiers and between voltage amplifiers and class A power amplifiers in audio work. It is preferable to transformer coupling in modern equipment because it is more economical and, in addition, usually gives better frequency response. This means it comes closer than transformer coupling does to amplifying equally all signals in the audio range.

Transformer coupling has not been used for many years between voltage amplifiers using vacuum tubes. However, you may find transformer-coupled transistor amplifiers, and there is some advantage to this type of coupling in transistor circuits.

A TYPICAL TUBE CIRCUIT

Fig. 1 shows two typical resistance-capacitance coupled stages. V_1 is the first stage; the output signal from this stage is fed to the second stage (V_2) by means of R-C coupling. The R-C coupling components are R_2 (which is the plate load resistor of V_1), C_3 (which is the coupling capacitor) and R_3 (which is the grid resistance for the second stage, V_2).

Let's review again the operation of these amplifier stages and how the coupling network works. With no signal applied to V_1, a current will flow from the cathode of the tube to the plate because the plate is con-

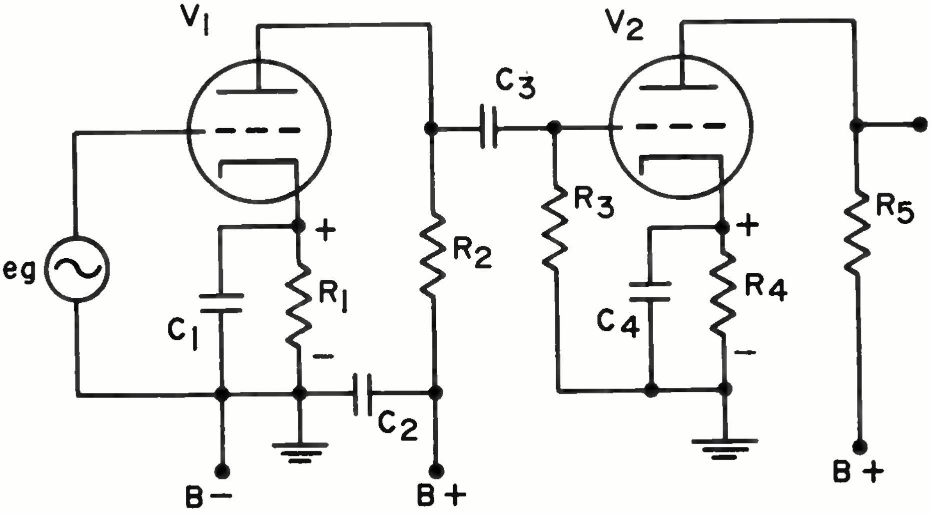

Fig. 1. Typical vacuum tube R-C coupled stage.

nected to the positive side of the B supply through R_2. The cathode is connected to the negative side through R_1. Electrons will leave the negative side of the B supply and flow through R_1 to the cathode. In flowing through R_1 they will set up a voltage drop across the resistor having the polarity shown. This voltage drop will make the cathode positive with respect to ground. The grid of V_1 is returned directly to ground through the generator and since there is no current flowing in the grid circuit there will be no voltage drop across the generator. Therefore the grid is at dc ground potential. This will make the grid negative with respect to cathode. The actual grid-cathode voltage will depend upon the size of R_1 and the current flow through R_1. The current flow through the tube can be determined from a tube manual and the required bias for the tube can be obtained simply by making R_1 large enough to produce the bias voltage needed.

Electrons reaching the cathode will be emitted by the cathode and flow through the tube to the plate. Then the electrons will flow from the plate through R_2 back to the B supply. In flowing through R_2 the electrons will produce a voltage drop across this resistor. The value of R_2 is usually quite high so there will be a substantial voltage drop across the resistor. Thus, although the plate will be positive with respect to ground, this positive voltage on the plate will be less than the positive voltage available at the positive terminal of the B supply.

The current flow through V_2 follows a path equivalent to the current path in V_1. The plate of V_2 is returned to the positive side of the B supply through R_5 so there will be a positive voltage on the plate of V_2. This will cause electrons to flow through R_4, producing a voltage drop across it (having the polarity shown) so that the cathode will be positive with respect to ground and the grid negative with respect to cathode. As before, there will be no current flow in the grid circuit and therefore no current flow through R_3. This means there will be no dc voltage drop across this resistor; consequently, the grid will be at dc ground potential.

When a signal voltage is applied by the generator e_g, the generator voltage will vary the voltage between the grid and cathode of V_1. The generator connects directly to the grid of V_1. The other side of the generator connects to the cathode through C_1. C_1 is chosen so that its reactance will be very low at the frequency of the signal to be handled. Thus we have the input signal from the generator applied directly between the grid and cathode of V_1.

When the polarity of the input signal is such that the grid end of the generator is positive and the other end is negative, the voltage applied between grid and cathode by the generator will subtract from the bias voltage across R_1. This will make the grid less negative with respect to the cathode and will cause the current flowing through V_1 to increase. This increase in current through V_1 will result in an increase in the voltage drop across R_2. Thus the voltage on the plate of the tube will become less positive with respect to ground; in other words, the plate voltage will swing in a negative direction.

When the signal applied by the generator reverses polarity, the grid will be made more negative and this will add to the bias voltage applied between the grid and the cathode of the tube. This will decrease the current flowing through the tube, which in turn will decrease the voltage drop across R_2. Therefore, the plate voltage on V_1 will swing in a positive direction.

Compare what we have in the plate circuit to the voltage applied to the grid by the generator. When the generator swings the grid positive, the plate voltage swings negative; when the generator swings the grid negative, the plate voltage swings positive. This means that the amplified signal voltage developed in the plate circuit of V_1 will be 180° out-of-phase with the input signal voltage eg.

The value of the coupling capacitor C_3 is chosen so that it has a low reactance within the range of signal frequencies we intend to amplify. As a matter of fact, the reactance of the capacitor is usually so low that for all practical purposes it acts like a direct connection for the signal voltages. Therefore, the voltage developed in the plate circuit of V_1 is applied directly to the grid of V_2 through the coupling capacitor C_3. The capacitor C_2 keeps the lower end of R_2 at signal ground potential. Often you will not find this capacitor in an amplifier; the actual capacitor is usually the output filter capacitor in the power supply. In any case, the signal voltage developed between the plate of V_1 and ground is coupled to the grid of V_2 through the coupling capacitor C_3 and to the cathode of V_2 through the cathode bypass capacitor C_4. Thus the amplified signal produced in the plate circuit of V_1 is coupled directly between the grid and cathode of V_2.

A TYPICAL TRANSISTOR CIRCUIT

Two R-C coupled transistor stages are shown in Fig. 2. Notice that both transistors are used in the common-emitter circuit and that both transistors are PNP transistors.

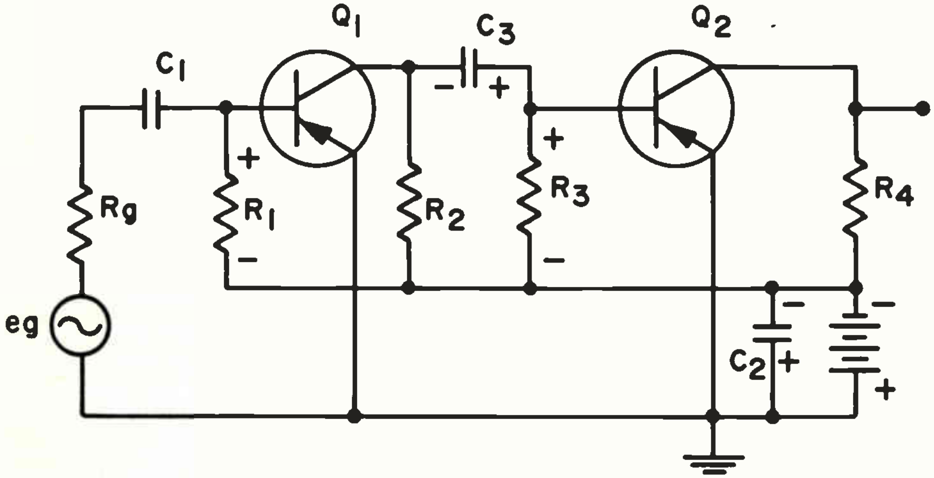

Fig. 2. Typical transistor R-C coupled stages.

The coupling components consist of R_2 (which is the collector load for Q_1), C_3 (the coupling capacitor) and R_3 (which is the base-bias resistor for Q_2).

Notice the capacitor across the battery. This is a large capacitor that effectively bypasses the battery as far as the signal is concerned, so that both the negative and positive sides of the battery are at ground potential in regard to the signal as well. In equipment designed for power line operation, the battery will be replaced by the power supply and C_2 will be the output filter capacitor.

Now let's review the operation of these two stages and see how a coupling network works. First, before any signal is applied, notice that the base of Q_1 and Q_2 connect to the negative side of the battery. The emitters of the two transistors connect to the positive side of the battery. This will place a forward bias across the emitter-base junction of the PNP transistor. However, the full battery voltage is not applied because there will be some small base current. A few of the holes crossing the emitter-base junction into the base will be filled by electrons that flow from the negative terminal of the battery through R_1 into the base of Q_1 and from the negative terminal of the battery through R_3 into the base of Q_2. Electrons flowing through resistors R_1 and R_3 will produce voltage drops across them having the polarity shown. The values of R_1 and R_3 are chosen so that the electrons flowing through them produce a voltage drop almost equal to the battery voltage. This will leave a forward bias across the emitter-base junction of only a few tenths of a volt.

Looking at the first stage, the emitter is connected to the positive side of the battery. This will pull electrons from the emitter, creating holes. The holes will be attracted by the negative potential on the base across the emitter-base junction, flow through the base and then across the base-collector junction and flow through the collector, where they will be filled by electrons coming from the negative terminal of the battery through R_2 to the collector. Thus we have a current flow through R_2 which will be governed by the number of holes reaching the collector of Q_1. This current flow through R_2 will result in a voltage drop across the resistor so that the negative potential on the collector of Q_1 will be somewhat less than the negative battery potential.

Holes and electrons move in the circuit for Q_2 in exactly the same way. Electrons pulled from the emitter of Q_2 create holes which flow through the transistor to the collector, where they are filled by electrons flowing through R_4.

When a signal voltage is applied by the signal source e_g the effective forward bias across the emitter-base junction of Q_1 is changed. Notice that we have shown a resistor in series with the generator. In the circuit for the vacuum tubes the generator will have some internal resistance, but since there is no current flow in the input circuit the resistance is of no consequence. However, in a transistor circuit there will be current flow in the input circuit and therefore the resistance affects the amount of signal actually reaching the transistor.

The capacitor C_1 is chosen to have a low reactance at signal frequency. Therefore the generator voltage is connected to the base of Q_1 through

R_g and C_1. The other side of the generator connects directly to the emitter.

When the end of the generator that connects to the base through the resistor and capacitor swings in a positive direction, the forward bias across the emitter-base junction of Q_1 will be reduced. This will cause the number of holes crossing the emitter-base junction and flowing to the collector to decrease. If fewer holes reach the collector then the number of electrons flowing through R_2 to fill these holes will go down. This means that the voltage drop across R_2 will decrease and the collector voltage will swing in a negative direction (in other words, closer to the negative battery potential).

When the generator polarity reverses so that the voltage applied to the base by the generator is negative, it will add to the forward emitter-base bias and cause the number of holes crossing the emitter-base junction to increase. This means that the number of holes reaching the collector will increase; therefore, the number of electrons flowing through R_2 to fill these holes must increase. The increase in current flow through R_2 will cause a greater voltage drop across this resistor. Thus, the potential at the collector of Q_1 will be less negative -- it will swing in a positive direction.

Notice the similarity between the transistor stage Q_1 and the vacuum tube stage V_1. In both cases, the signal is inverted; the amplified output signal voltage is 180° out-of-phase with the input signal voltage.

The amplified signal at the collector Q_1 is coupled to the base of Q_2, through the coupling capacitor C_3. This is similar to the arrangement used between the vacuum tubes in Fig. 1, but there is something quite different about the circuit. In the vacuum tube circuit shown in Fig. 1, there is no current flow through the grid resistor R_3 nor is there any current flowing between the cathode and grid of the tube. R_3 is a large resistor -- its purpose is to take care of any electrons that accidentally strike the grid of the tube and provide a path for these electrons back to ground. In most amplifier tubes this current flow through R_3 is so small it cannot be measured and we say for all practical purposes there is no current flow. This means that C_3 is coupling the signal into a very high impedance circuit.

In the circuit shown in Fig. 2, there is a current flow through R_3. However, the current flow through R_3 is small and the value of this resistor is comparatively large. Also, there is current flowing across the emitter-base junction. This is the movement of holes across this junction and since they flow across the junction with relatively little impedance with the forward bias on the transistor, we have, in effect, a low resistance circuit between the emitter and base. This is the circuit into which the capacitor C_3 must couple the signal. C_3 must be chosen so it has a low reactance compared to the input resistance of Q_2. Since the input resistance of Q_2 is quite low, the capacity of C_3 must be quite large in order to provide the low reactance coupling needed.

Often in transistor R-C coupled circuits, you will see electrolytic capacitors used as the coupling capacitor. In a circuit such as the one in Fig. 2 we have indicated the polarity with which an electrolytic capacitor should be connected.

The amplified signal from Q_1 is fed through C_3 to the base of the transistor. This causes the forward bias on Q_2 to vary, which in turn varies the number of holes flowing through the transistor and the electron current flow through R_4.

Q_2 will invert the signal 180° just like Q_1 did. Therefore, the signal voltage across R_4 will be in phase with the generator voltage. The signal voltage polarity will be inverted 180° by the amplifier stage Q_1 and will be inverted another 180° by the second amplifier Q_2 so that the output of the two-stage R-C coupled amplifier will be in phase with the input signal voltage. Of course, the same is true of the two-stage vacuum tube amplifier circuit.

When we discussed both the vacuum tube circuits shown in Fig. 1, and the transistor circuit shown in Fig. 2, we said that the coupling capacitor must have a low reactance. However, you know that the reactance of the capacitor varies with the frequency. Therefore, the reactance of these coupling capacitors must vary with the frequency; therefore, their effectiveness as coupling devices must also vary as the frequency varies. This fact has an effect on the limits of the frequencies which an amplifier of this type can amplify. There are other factors in the circuit which also limit the range of frequencies these amplifiers can handle and since these factors appreciably affect the performance of the amplifiers we will investigate them now.

FREQUENCY RESPONSE

When we talk about the frequency response of an amplifier we mean the ability of the amplifier to amplify signals of different frequencies. For example, if we say that the frequency response of an amplifier is flat from 100 cycles to 10,000 cycles we mean that signals from 100 cycles up to 10,000 cycles will receive the same amount of amplification. If we say that the frequency response of an amplifier falls off below 100 cycles and above 10,000 cycles we mean that signals having a frequency less than 100 cycles and signals having a frequency above 10,000 cycles do not receive as much amplification as signals between 100 cycles and 10,000 cycles receive.

Amplifiers can be designed to have a very wide frequency response -- in other words, they can amplify a wide range of frequencies. Often, however, it is not advantageous to have an amplifier that can amplify an extremely wide range of frequencies. For example, there is a limit to how low or to how high an audio frequency we can hear. Therefore, there is very little point in designing an amplifier that can amplify signals many times the frequency of the highest frequency we can hear. Certain economies can be realized by designing an amplifier that will amplify the desired or required frequency range and very little more. In addition to these economies, the design of the amplifier is usually simplified if we do not try to extend the frequency range it can amplify too much.

The factor that usually limits the frequency range of an amplifier most is the coupling network used between the various stages of the amplifier. In the circuits shown in Figs. 1 and 2 there are a number of factors that will limit the high-frequency and the low-frequency responses of these amplifiers. Let's look at these fac-

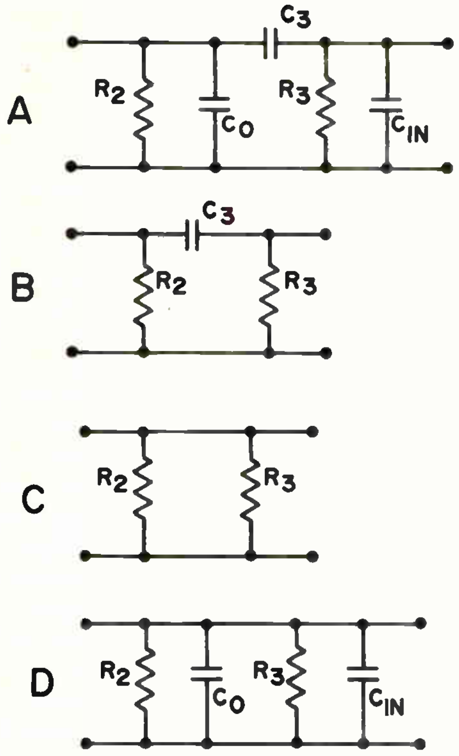

Fig. 3. Equivalent circuits of coupling network between V1 and V2 in Fig. 1.

tors and examine them in detail. We will consider the vacuum-tube circuit shown in Fig. 1 first.

In Fig. 3A we have shown a complete equivalent circuit of the coupling circuit used between V_1 and V_2. Notice that the plate resistor R_2 is shown in the circuit, as well as the coupling capacitor C_3 and the grid resistor R_3. In addition to these components we have also shown a capacitor marked C_O and a second capacitor marked C_{IN}. C_O represents the output capacity of V_1. This will be made up of the capacity in the tube itself plus wiring capacity in the circuit. C_{IN} is the input capacity of V_2. This will be the grid-to-cathode capacity plus any additional capacity added to the circuit by the wiring in the circuit. These capacitors are not shown on the diagram in Fig. 1, but they are present in the circuit and will affect the operation of the circuit.

At low frequencies, the output capacity of V_1 and the input capacity of V_2 are too small to appreciably affect the operation of the coupling network. We have shown the equivalent low-frequency circuit in Fig. 3B. Notice that the only components shown in this circuit are the plate resistor R_2, the coupling capacitor C_3, and the grid resistor R_3.

At some low frequency, the reactance of C_3 will be equal to the resistance of R_3. As you will remember, the capacitive reactance of C_3 increases as the frequency goes down. Even though the value of R_3 may be made quite large, if the frequency of the signal applied to the circuit is low enough a point will eventually be reached where the reactance of C_3 will be equal to the resistance of R_3. When this happens, C_3 and R_3 act as a voltage divider network so that only part of the voltage dropped across R_2 actually appears across R_3 and is fed to the grid and cathode of V_2.

By means of a vector diagram, we can see what happens to the voltage across R_3 when the reactance of C_3 is equal to the resistance of R_3. Remember that when a voltage is applied to a purely resistive circuit, a current will flow which will be in phase with the voltage. On the other hand, when a voltage is applied to a purely capacitive circuit, a current will flow that leads the voltage by 90°. When a voltage is applied to a circuit which has an equal resistance and an equal capacitive reactance, a current will flow in the

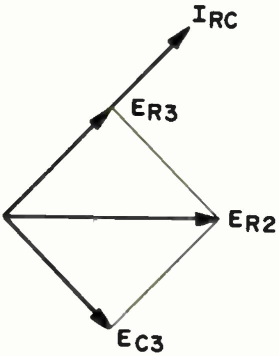

Fig. 4. Vector diagram of input and output voltages at low frequencies.

circuit that leads the voltage by 45°. From this information we can draw a vector diagram to show how the voltage across R_2 is divided across C_3 and R_3.

Fig. 4 is a vector representation of the voltage division. To draw this diagram the first thing we do is draw E_{R2}, which represents the voltage across R_2. Next, we draw the current I_{RC}, which represents the current that will flow through the network consisting of C_3 and R_3. We draw this current vector leading the voltage across R_2 by 45°. Now, we know that the voltage across C_3 will lag the current flowing through it by 90°. Therefore we can draw the vector E_{C3} lagging the vector I_{RC} by 90°. We also know that the voltage across R_3 will be in phase with the current flowing through it. This means that the voltage vector E_{R3} will fall on the vector I_{RC}. This will tell us the direction in which the vector representing the voltage across R_3 should point.

We know that the voltage across C_3 plus the voltage across R_3 must be equal to the voltage across R_2. Therefore, by drawing perpendiculars from the end of the vector representing the voltage across R_2 to the vectors representing the voltage across R_3 and C_3 we can determine the amplitude of the voltage across R_3 and across C_3. The perpendiculars are shown in Fig. 4. If we carefully measured the voltage vector E_{R3} we would find that it was equal to .707 × E_{R2}. Similarly, the voltage across C_3 will be equal to .707 times the voltage across R_2. Thus, even though the capacitive reactance is equal to the resistance, the actual voltage that will appear across R_3 and be fed to the second stage will be slightly over 7/10ths the input voltage, where at first we might think that the voltage would be only half the input voltage.

The frequency at which the reactance of the coupling capacitor is equal to the resistance of the input resistor of the second stage is called the half-power point. The reason for this is that the current that will flow through the grid resistor will depend upon the voltage applied to it.

If the voltage at some frequency where the capacitive reactance of the capacitor is so small it can be ignored is 1 volt, then with the same amplitude signal across R_2, at the frequency where the reactance of the capacitor is equal to the resistance of the grid resistor, the voltage across the resistor will be .707 volts.

In this case, the current that will flow through the grid resistor will be .707 times what it would be when the voltage across the resistor was 1 volt. Therefore the power of the signal fed to the resistor will be equal to the voltage times the current which will be $.707E \times .707I = .5P$. Thus the power fed to the resistor will be one half the power at frequencies where the coupling capacitor can be ignored.

The equivalent diagram of the coupling circuit at mid-frequencies is shown in Fig. 3C. Here, the reactance of the coupling capacitor C_3 is so small compared to the resistance of R_3 that it can be ignored. Therefore for all practical purposes R_2 and R_3 are connected directly in parallel. R_3 is usually many times the resistance of R_2 so that it has very little effect as far as reducing the size of the plate load of V_1 is concerned. In the mid-frequency range the output capacity of V_1 and the input capacity of V_2 are too small to affect the operation of the circuit so they can be ignored. In this mid-frequency range, essentially all of the output signal developed by V_1 is fed to V_2 so that the coupling circuit operates with maximum efficiency.

At high frequencies the reactance of C_3 will be even smaller and can therefore be omitted from the circuit. However, the effects of the output capacity of V_1 and the input capacity of V_2 must be considered. They are shown in Fig. 3D, the equivalent circuit for high frequencies. Notice that once again R_2 and R_3 are, in effect, in parallel; also C_O and C_{IN} are likewise in parallel. Therefore the circuit acts as if there is one capacitor connected across the parallel combination of R_2 and R_3.

As the frequency of a signal increases, you know that the capacitive reactance decreases. At low and middle frequencies the capacitive reactance of C_O and C_{IN} in parallel is so high that it has no effect on the performance of the circuit. However, as the frequency increases, the capacitive reactance of this parallel combination goes down. At some high frequency, the capacitive reactance will eventually be equal to the resistance of R_2 and R_3 in parallel. At this point the effective plate load resistance on V_1 will be reduced and the output voltage developed by V_1 will also go down.

When the capacitive reactance of the parallel capacity is equal to the resistance of R_2 and R_3 in parallel, then half of the signal current developed by V_1 will flow through the resistance combination and the other half will flow through the capacitors. This means that the voltage developed in the output of V_1 will be reduced. By means of the vector diagram shown in Fig. 5, we can see exactly what happens.

First, we draw the current vector I which represents the signal current from V_1. Then we draw a voltage vector E_R to represent the voltage developed across the parallel combination of R_2 and R_3. We draw this vector in phase with the current because we know that the voltage developed across these resistors will be in phase with the current. Now we draw a voltage vector that lags the current by 90°. This vector represents the voltage developed across the capacitors. Since half the current is flowing through the resistance and half through the capacitance, the two voltages must be equal; therefore, we draw the voltage vector E_C equal to the voltage vector E_R and lagging by 90°. Now we perform the vector addition of these two voltages as shown in Fig.

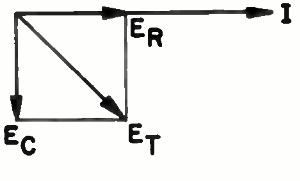

Fig. 5. Vector diagram of input and output voltages at high frequencies.

5. This gives us the total output voltage from V_1. Again, this voltage will be equal to .707 times the voltage developed in the mid-frequency range. This is the half-power point at the high-frequency end of the frequency range.

In addition to the amplitude of the signal voltage reaching V_2, dropping off both at high frequencies and at low frequencies, you should also notice that the phase of the voltage is changed. In the mid-frequency range, the voltage applied to V_2 will be in phase with the output voltage from V_1. However, at the low-frequency half-power point, the voltage fed to V_2 will lead the output voltage from V_1 by 45°. At the high-frequency half-power point, the voltage applied to V_2 will lag the output voltage from V_1 by 45°. In sound or audio amplifiers this phase shift is not particularly important, but in video amplifiers and television receivers this phase shift is important and can produce a smear in the picture. You will learn more about this later, as well as how this problem is overcome.

We have a somewhat similar situation in the transistor amplifier circuit shown in Fig. 2. However, here the situation becomes even more complicated because the transistors are low-impedance devices whereas tubes are high-impedance devices.

Fig. 6A illustrates the effective coupling circuit between Q_1 and Q_2 in Fig. 2. First, looking at Fig. 6A you see a resistor marked R_o. This resistance represents the output resistance of Q_1. In parallel with this we have shown R_2, the collector-load resistor. We have also shown C_O which represents the output capacitance of Q_1 plus any distributed capacitance that may be in the circuit. The coupling capacitor C_3 is shown as before; R_3 represents the resistance connected in the input circuit of Q_2. In parallel with R_3 we have shown another resistor marked R_{IN}. This resistance represents the input resistance or the base-emitter resistance of Q_2. In parallel with this combination we have capacitor C_{IN} which represents the input capacitance of Q_2. At some frequencies all of these parts affect the performance of the circuit.

Fig. 6B illustrates the equivalent low-frequency circuit of the coupling network. Here we have represented the output resistance of Q_1 and R_2 as a single parallel resistance. Since these two resistors are always in parallel we will use this representation in all of the equivalent circuits. Similarly, we have represented R_3

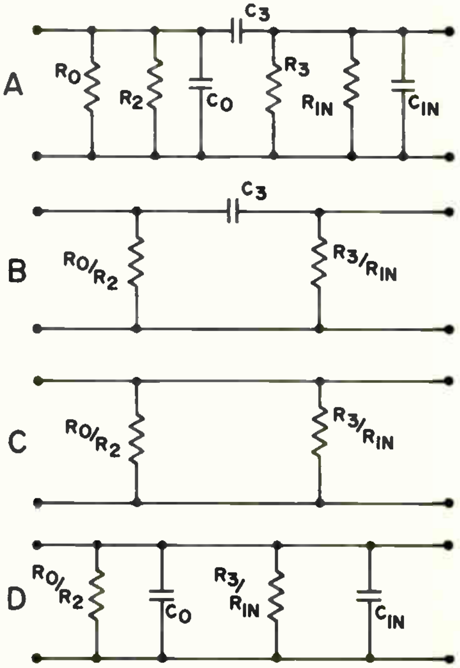

Fig. 6. Equivalent circuit of coupling network between Q1 and Q2 in Fig. 2.

and the input resistance of Q_2 as a single resistance. C_3 is the coupling capacitor and at low frequencies it will have a reactance that must be considered.

Since the input resistance of Q_2 is actually the parallel combination of R_3 and the input resistance to the transistor, we see that this resistance may be quite low. You already know that the input resistance of the transistor of a common emitter circuit is not particularly high; therefore, this resistance in parallel with R_3 will result in a comparatively low total resistance. Thus if we are to keep the half-power point at a reasonable frequency, we must use a large capacity for C_3. Capacitors many times those required for vacuum tube circuits are found in coupling networks between transistor stages. At some frequency the reactance of C_3 will be equal to the parallel resistance in the input circuit of Q_2 and then we will have the same voltage division we had in the vector circuit shown in Fig. 4. The amplitude of the voltage reaching the transistor Q_2 will be .707 of the amplitude reaching it in the mid-frequency range.

In Fig. 6C we have shown the effective mid-frequency range circuit. Here we simply have all of the resistances in parallel. Notice that since the input resistance of Q_2 is, in effect, in parallel with the output resistance of Q_1, the input resistance has an effect on the output resistance into which Q_1 is working. This means that in transistor R-C coupled amplifiers the input resistance of the second stage can actually affect the output that will be obtained from the first stage. This is not true in vacuum-tube coupled circuits because the input resistance of the second stage is so high it will not affect the output resistance of the first stage.

Fig. 6D shows the equivalent high-frequency circuit. We have shown the two resistances and capacitances separately, but actually they could be lumped together so that we have, in effect, a single resistance and a single capacitance. As in the case of the vacuum-tube circuit, at some frequency the capacitive reactance of the parallel capacity will be equal to the resistance of the parallel resistors. When this happens, the output voltage developed by Q_1 will fall to .707 of the voltage developed in the mid-frequency range. The vector representation will be the same as that given in Fig. 5.

We mentioned that the coupling capacitor in a transistor circuit must be larger than in a tube circuit in order to keep the low-frequency half-power point at a reasonably low frequency. In other words, we have an additional problem in the transistor circuit because of the low input resistance of the second transsistor. At the high frequency end we have a somewhat different situation. Since the transistors are already low-resistance devices, the value of the output and input capacitances can be somewhat larger than in a vacuum-tube circuit before they cause appreciable difficulty. If they happen to be the same as those in a vacuum tube circuit, then the high-frequency half-power point in a transistor circuit will be somewhat higher than the vacuum-tube circuit because the vacuum-tube circuits are high-resistance circuits and are quickly loaded by a capacitive reactance. The transistor circuits, on the other hand, are low-resistance circuits and the high-frequency half-power point will not be reached until a somewhat higher frequency.

CASCADE AMPLIFIERS

At the half-power point we say that the gain of an amplifier is .707 times the gain of the amplifier middle frequency. We also express this quite frequently as the percentage and say that the gain is 70.7% of the gain in the middle frequency range. This drop-off in gain due to the coupling network between a single stage is not too troublesome when only one network is concerned, but sometimes we have a number of amplifiers called cascade amplifiers and here the problem becomes much greater.

Cascade amplifiers are just a number of amplifiers connected together. A diagram of four cascade amplifiers is shown in Fig. 7. Here the input signal is fed to amplifier 1, amplified by it and then fed to amplifier 2, amplified further and fed to amplifier 3, where it is amplified still more, fed to amplifier 4, and amplified again.

We have not shown actual circuits in this diagram but we have presented each stage as a block to simplify the diagram. Each of these amplifiers could be either a vacuum tube amplifier or a transistor amplifier.

If the gain of each amplifier is 10 in the middle frequency range of about 100 cycles to 10,000 cycles, then the over-all gain of the first two stages is 10 × 10, or 100. The gain of the first three stages is 100 × 10 or 1000, and the gain of all four stages is 10,000. Thus, in the middle frequencies where the gain of each stage is 10, the total gain of this system is 10,000.

Now let's assume we are interested in amplifying signals as low as 75 cycles and at that frequency, the gain of the amplifier drops to 70.7% of what it is in the middle frequency range. Here the gain of each stage would be 7.07. Now the gain of the first two stages is 7.07 × 7.07 = 50. Now notice that the voltage gain of the two stages is only half of what it was at the middle frequencies.

The gain of the first three stages will be 50 × 7.07 or a little over 350, and the gain of all four stages will be 7.07 × 7.07 × 7.07 × 7.07 = 2500. Notice that whereas the gain of each stage has fallen to 70.7% of the gain at the middle frequencies, the over-all gain of the amplifier is only 25% of what it was at the middle frequencies! Thus, you can see that although the decrease in gain to 70.7% is not too big a problem in a single coupling network, if we have a number of stages used together, this fall-off in output is cumulative, so that in the four stages coupled as in Fig. 7, we have a gain of only 25% of the gain we had at the middle frequency. Of course, this much drop in response could not be tolerated and we would

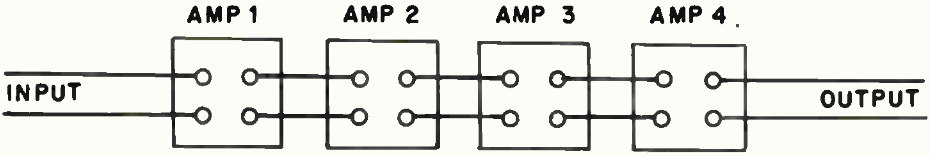

Fig. 7. Block diagram of cascade voltage amplifiers.

have to design each stage a little better so that within the range of frequencies we wanted to amplify, the gain in each stage would remain almost constant. In the example we have given, this problem can be overcome by using larger coupling capacitors.

SUMMARY

Resistance-capacitance coupled voltage amplifiers are the most important type of audio amplifier you will encounter. You should be able to draw from memory the circuits shown in Fig. 1 and in Fig. 2. You will use these circuits over and over again and the sooner you know exactly how the circuits are connected, the faster you'll reach a point where you'll understand their operation completely.

In the two circuits the first stage amplifies the input signal voltage. The amplified signal voltage is developed across the load resistor R_2. This amplified voltage is then fed through the coupling capacitor C_3 to the following stage. As long as the reactance of C_3 is low compared to the input resistance of the following stage all of the signal developed across R_2 reaches the input circuit of the following stage. However, at low frequencies the reactance of C_3 becomes appreciable compared to the input resistance of the following stage and then part of the signal is lost across C_3 so that the entire signal does not reach the input of the following stage. Thus in a low-frequency range the gain of the two-stage amplifier begins to fall off.

At some high frequency the output capacitance of the first stage and the input capacitance of the second stage begin to have a low enough reactance to effectively shunt the circuit and reduce the signal voltage developed across the load resistor R_2. When this happens, the gain of the amplifier begins to fall off as it does at low frequencies due to the reactance of the coupling capacitor. Because the input resistance of a transistor amplifier is much lower than that of a tube amplifier, a much larger coupling capacitor is required in the low-frequency region in the transistor circuit than is required in a tube circuit.

In the case of the transistor amplifier there was a tendency for the shunting capacity to have a less serious effect on the gain of the amplifier than it had in the case of the tube amplifier. This was due to the fact that the output resistance of the first transistor and the input resistance of the second stage were already low; therefore, a much larger capacitance was required to have the same loading effect. The input resistance of the second stage in a transistor amplifier had an appreciable effect on the gain of the first stage -- this is not true in the case of a vacuum tube amplifier; the input resistance of the second stage in the latter type is so high that it will not have any effect on the value of the load resistance in the plate circuit of the first stage.

Be sure that you understand resistance-capacitance amplifiers thoroughly before leaving this important section of the lesson. After you're sure that you understand the amplifiers, check yourself by doing the following self-test questions.

SELF-TEST QUESTIONS

(a) What is the purpose of R_1 in the circuit shown in Fig. 1?

(b) What is the purpose of C_1 in Fig. 1?

(c) With respect to the input signal voltage, what will the polarity of the amplified signal voltage across R_2 be?

(d) Is the voltage drop across R_1 in Fig. 2 used as the forward bias on Q_1?

(e) In the circuit shown in Fig. 2, do the holes reaching the collector flow through the collector load resistor R_2?

(f) When the input signal from the generator in Fig. 2 has a polarity which causes the end that connects the emitter to be negative and the end that connects to and through C_1 to the base to be positive, what happens in the transistor?

(g) Why does the input resistance of Q_2 in Fig. 2 have an effect on the gain of Q_1?

(h) In the circuits shown in Figs. 1 and 2, what part primarily limits the lower frequency limit of the two amplifiers?

(i) In the same circuits, what limits the high frequency limit to which the amplifiers can be used?

Transformer-Coupled Voltage Amplifiers

In the early days of radio, the vacuum tubes manufactured were relatively crude, and you couldn't get a great deal of gain from them. Voltage amplifiers with vacuum tubes frequently used transformer coupling between the tubes because the gain of the stage could be increased considerably by using a step-up transformer. For example, suppose the tube had a gain of five and you used a step-up transformer between the tube and the following stage, and suppose that the transformer had a turns-ratio of 1 to 3; this meant that the transformer would step-up the signal voltage fed to the primary by a factor of 3. Therefore, the total gain obtained with the tube and transformer would be equal to 5 × 3, or 15.

With modern vacuum tubes it is comparatively easy to obtain a gain of nearly 100 in R-C coupled circuits. Since R-C coupling is much more economical than transformer coupling, you will not find transformer coupling between voltage amplifier stages in modern equipment. Therefore, we'll take only a quick look at a vacuum-tube voltage amplifier using transformer coupling so you will know what it looks like, in case you run into it in any older equipment you might service, and also because transformer coupling is still used in some other applications.

In transistor circuits an entirely different situation exists. We have already pointed out that the input resistance of the second stage in a two-stage transistor amplifier has an effect on the output resistance of the first stage. We pointed out that the low input resistance of the second stage will, in effect, reduce the load resistance of the first stage, which in turn will reduce the amplitude of the output signal from the first stage. This problem can be overcome by using transformer coupling between the two stages. The transformer serves as an impedance-matching device and prevents the low input resistance of the second stage from reducing the load resistance of the first stage. Today, transformer coupling is much more important in transistorized circuitry than in vacuum circuity, so we'll spend more time discussing this type in transistorized circuits. However, let's go ahead and look at a transformer-coupled vacuum tube amplifier first.

VACUUM-TUBE CIRCUITS

Fig. 8 illustrates a typical two-stage vacuum-tube amplifier using transformer coupling between the stages. The operation of the circuit is comparatively simple. Resistor R_1 provides bias for V_1, and C_1 is the cathode bypass which provides a low-impedance bypass around the resistor for the signal. Resistor R_2 similarly provides bias for the second stage, V_2, and it is bypassed for the signal by capacitor C_2.

The input signal voltage causes the

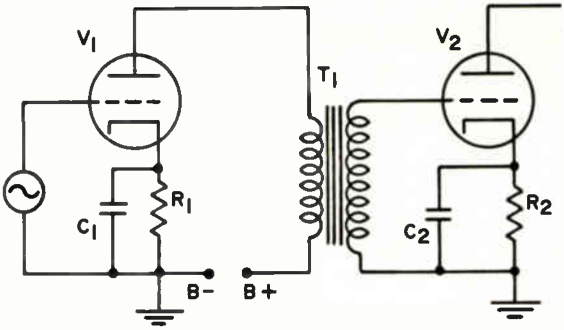

Fig. 8. Two transformer-coupled vacuum tubes.

potential between the grid and cathode to vary. This causes the plate current flowing through V_1 to vary. This varying current flows through the primary of T_1 and sets up a varying magnetic field which induces a voltage in the secondary of T_1. T_1 is a step-up transformer so that the voltage across the secondary will be greater than the voltage across the primary.

The amplified and stepped-up voltage appearing across the secondary of T_1 is applied between the grid and cathode of V_2 where it will receive further amplification.

At first glance it might appear that the transformer-coupled two-stage amplifier has many advantages over the R-C coupled amplifier. However, as we pointed out before, the step-up feature of the transformer is not needed with high-gain vacuum tubes available to use in modern equipment. In addition, a transformer is much more costly than the two resistors and capacitor needed for an R-C coupled network. Furthermore, most transformers are quite frequency-sensitive and therefore the signal voltage reaching V_2 will vary appreciably with frequency. Some of the problems of frequency discrimination in the transformer can be overcome by careful design, but this in turn increases the cost of the transformer. Because of the disadvantages of the transformer and the availability of high-gain tubes, this circuit is not used in modern equipment.

TRANSISTOR CIRCUITS

A transistor voltage amplifier using transformer coupling is shown in Fig. 9. Notice that both transistors are connected in common-emitter circuits.

From a standpoint of getting maximum gain from a transistor amplifier, transformer coupling is actually the best arrangement that can be used. You will remember that the input impedance of a transistor is quite low. We also pointed out that when two transistors are coupled together by means of resistance-capacity coupling, the low impedance of the second transistor actually loads the first transistor. The two transistors are not matched. By means of a transformer the first transistor can be matched to the second transistor so that the undesirable effect of having the input circuit of the second transistor load the output circuit of the first transistor can be avoided. The transformer serves as an impedance-matching device to match the comparatively high impedance of the first transistor to the low input impedance of the second transistor.

Looking at Fig. 9 we see that we have a transformer, T_1, in the input. This transformer is a step-down transformer and matches the low input impedance of the first transistor to the preceding circuit. C_1 is a blocking capacitor. It is needed to keep the transformer secondary from shorting out the forward bias placed across the emitter-base junction. The bias on the junction is obtained from the battery by means of a voltage divider network consisting of both R_1 and R_3. This network will bias the base negative with respect to the emitter. Notice that the 3K resistor R_1 is connected directly across the input circuit. As for the signal, it is connected directly from the base to the emitter. The 4 mfd capacitor C_3 provides an effective signal bypass between the emitter and ground.

The resistor R_2 is placed in the circuit to prevent thermal runaway. You will remember we mentioned previously that minority carriers crossing the collector-base junction may increase the forward bias across the emitter-base junction. This causes the current flow through the transistor to increase, heating the collector-base junction and its resistance, thereby causing still more minority carriers to cross the junction and increase the forward bias still further. R_2 prevents this from happening because if the emitter current increases, the voltage across R_2 increases, and this voltage subtracts from the forward bias across the emitter-base junction. This tends to keep the current through the transistor constant.

The signal is applied through the 4 mfd capacitor to the base of the first transistor and from the other end of the transformer through C_3 to the emitter. This causes the number of holes crossing the emitter-base junction to vary which in turn causes the number of holes reaching the collector to vary. Then the negative flow from the negative ter-

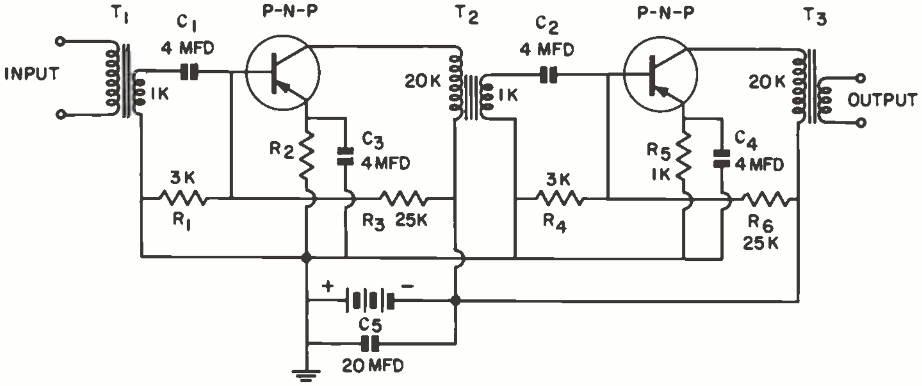

Fig. 9. Transformer-coupled voltage amplifier using transistors.

minal of the battery through the primary of T_2 will vary. The varying current through the primary of the transformer produces a magnetic field which induces a voltage in the secondary of the transformer. This in turn produces a varying voltage between the base and emitter of the second transistor.

Notice that the primary of T_2 is marked 20K and the secondary is marked 1K. The output impedance of a transistor in a common-emitter circuit is about 20K. The input impedance is about 1K. By means of a step-down transformer these impedances can be matched. You will remember that maximum power transfer from a generator to the load occurs when the load impedance is matched to the generator impedance. The first transistor acts more or less as a generator and maximum power is transferred from it to the second transistor when the input impedance of the second transistor is matched to the output impedance of the first transistor.

You might wonder why we are concerned about matching impedances to get maximum power transfer when the circuit shown in Fig. 9 is supposed to be a voltage amplifier. Remember, however, that transistors are current-operated devices. Therefore by matching impedances we can get maximum current variation in the emitter-base circuit of the second transistor. This in turn will result in maximum current variation in the collector circuit. The higher the current variation through the load of the second transistor the greater the voltage amplification obtained will be.

A two-stage transformer-coupled amplifier such as is shown in Fig. 9 will yield far more voltage gain than the two-stage R-C coupled amplifier shown in Fig. 2. This might at first lead you to believe that transformer coupling should be used in all transistor voltage amplifier circuits. However, this is not true because the transformers needed for the transformer coupling are much more expensive than the two resistors and capacitor needed in R-C coupled circuits. As a matter of fact, since transistors themselves are relatively inexpensive, it is usually more economical to use a three-stage R-C coupled voltage amplifier than it is to use a two-stage transformer-coupled voltage amplifier.

A three-stage R-C coupled amplifier is capable of giving about the same gain as a two-stage transformer-coupled amplifier. In addition, it is more difficult to get good frequency response using transformer coupling than it is using R-C coupling. Therefore, in applications in which we are concerned about the frequency response and in which we are trying to keep the cost down it is usually advantageous to use a three-stage R-C coupled amplifier. However, in some applications you will find transformer-coupled voltage amplifier circuits.

If you have to replace a transformer in a transformer-coupled voltage amplifier, it's important to use a replacement transformer having the same turns-ratio as the original transformer. The transformer is primarily an impedance-matching device and if you do not use a transformer with the same turns-ratio as the original, the output impedance of the first transistor will not properly match the input impedance of the second transistor.

SUMMARY

Since it is uneconomical, transformer coupling between voltage-amplifier vacuum-tube stages is no longer used. You will find it only in very old equipment. The transformer used between vacuum-tube voltage-amplifier stages is usually a step-up transformer. Transformer coupling is used in some transistor amplifiers. In this application, the transformer is a step-down transformer and it is primarily an impedance-matching device. By using a transformer in transistor voltage amplifiers, the high output impedance of the first transistor can be matched to the low input impedance of the second transistor. Transistor voltage amplifiers are capable of higher gain than R-C coupled amplifiers, but by using an extra stage the same gain can be obtained from R-C coupled amplifiers.

SELF-TEST QUESTIONS

(j) Why was transformer coupling used between vacuum tubes in the early days of radio?

(k) Why are transformer-coupled voltage-amplifier stages using tubes no longer used?

(l) Why is it better to use transformer coupling in transistor-voltage amplifier stages?

(m) Why is transformer coupling seldom used between transistor-voltage amplifier stages?

(n) What must you watch if you have to replace a transformer in a transformer-coupled transistor-voltage amplifier?

Single-Ended Power Amplifiers

The primary purpose of most low-frequency amplifiers is to build up an audio signal to a sufficient amplitude to drive the loudspeaker. A loudspeaker must be driven by a power amplifier. The voltage amplifiers we have discussed previously are used to amplify a low-voltage audio signal to a sufficient amplitude to drive a power amplifier, which in turn will drive the loudspeaker.

There are a number of different types of power amplifiers that can be used to drive a loudspeaker: the single-ended power amplifier, which is always a Class A power amplifier, and the double-ended power amplifier, which may be a Class A, Class AB or Class B power amplifier. In this section of the lesson we are going to discuss single-ended power amplifiers. We will discuss both vacuum-tube power amplifiers and transistor power amplifiers.

Today, there are millions of radio and television receivers in use with low-frequency single-ended power amplifiers using vacuum tubes. You can be sure that you will run into this type of amplifier to service. In addition, there are many single-ended power amplifiers using transistors. This type of power amplifier is found in modern automobile receivers as well as in many portable receivers, in some table model radios and in some transistorized television receivers. It is quite likely that in the future there will be fewer vacuum tube stages around to service, but at the present there are probably many more power amplifiers using vacuum tubes than transistors. We will go into the vacuum-tube circuit first, and then into the transistor power amplifiers later.

VACUUM-TUBE CIRCUITS

A typical single-ended Class A power amplifier using a beam power tube is shown in Fig. 10. Practically all modern low-frequency power amplifiers use beam power tubes. This stage is driven by the amplified signal voltage from the last voltage amplifier applied to R_1 through C_1. It produces audio power to drive the loudspeaker. Notice that in general this circuit is not too different from that of a voltage amplifier.

The tubes made for use in power amplifier stages are designed especially for this type of service. These tubes normally draw a much higher plate current than the tubes in voltage amplifiers. A typical tube used in a voltage amplifier may draw a plate current somewhere between about 1 and 10 milliamperes, whereas tubes designed for use in power amplifiers will usually draw a plate current of 50 milliamperes or more.

In the circuit shown in Fig. 10, R-C coupling is used between the preceding voltage amplifier and the power amplifier. This type of coupling can be used between a Class A power amplifier and the last voltage amplifier because no grid current flows. The power amplifier shown in Fig. 10 is designed to operate as a

Class A amplifier by the voltage developed across the cathode-bias resistor R_2. You will remember that in a Class A amplifier, sufficient bias is applied to the tube so that the grid voltage is halfway between zero and cut-off voltage. In operation, the grid should not be driven positive, and it should not be driven into the region where plate current is cut off. As long as the grid is not driven positive, there will not be a grid current flow.

Notice that R_2 is bypassed by a capacitor, C_2. This capacitor is usually an electrolytic capacitor -- in many receivers you will find that this capacitor is in a common can along with the filter capacitors used in the receiver. It is usually a comparatively low-voltage capacitor because the voltage across it (which is equal to the voltage across R_2) is not too high. An electrolytic capacitor is used because the resistance of R_2 is usually only a few hundred ohms. A large capacitor is required to bypass this resistor -- otherwise, the reactance of the capacitor becomes so high at low frequencies that the resistor is not bypassed effectively. The purpose of this capacitor is to hold the cathode at signal ground potential, as we mentioned previously, so that the input signal is, in effect, applied directly between the grid and cathode of the tube.

You will remember that to get maximum power transfer from a generator to a load, the load impedance must be matched to the generator impedance. In this circuit, the tube acts as the generator. However, a beam power tube has a very high plate impedance. Therefore, it is not practical to try to match the plate impedance of the tube to the speaker. Instead, manufacturers of the tubes usually specify a load impedance into which a tube should work for best results. The output transformer is designed so that the tube will, in effect, see this load impedance. This is accomplished by means of a step-down transformer, T_1, which matches the load impedance of the tube to the low impedance of the speaker voice coil. Another way of looking at this transformer is from the speaker end of the circuit. Most speakers have a comparatively low impedance; the speakers in most radio and television receivers have a voice coil

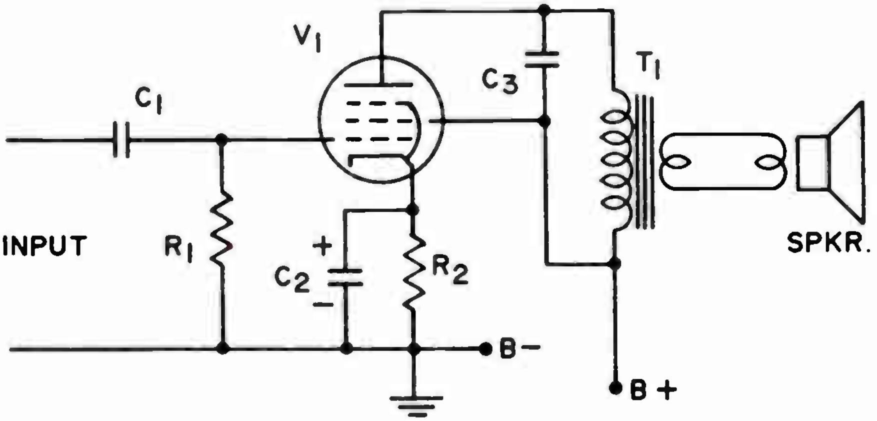

Fig. 10. Schematic diagram of single-ended Class A amplifier using a beam power tube.

impedance of 3.2 ohms at a frequency of 400 cycles. The output transformer is designed to step up this impedance so that the tube sees the load it works into best. Most beam power tubes work into a load of somewhere between 2,500 ohms and 10,000 ohms. Therefore, if we look at the circuit from the speaker end, the transformer is a step-up transformer because it steps up the low impedance of the speaker to the higher impedance of the tube. If we look at the circuit from the tube end, on the other hand, the transformer is a step-down transformer because it steps the high impedance of the tube down to the low impedance of the speaker. The important thing for you to realize is that the primary winding of the transformer, which connects to the plate circuit of the tube, has far more turns on it than the secondary winding that is connected to the voice coil of the speaker. Since the primary winding has more turns than the secondary, we usually refer to this as a step-down transformer.

Capacitor C_3 is called a plate bypass capacitor. This capacitor is used to prevent oscillation. Actually, the capacitor provides a low-impedance path for high-frequency signals and it reduces the possibility of a high-frequency oscillation in the stage. These high-frequency signals in the plate circuit of the tube are shunted to ground through the capacitor while low frequency signals must flow through the primary of T_1. You might wonder how the high-frequency signals are shunted to ground through C_3, since C_3 connects between the plate and screen of the tube. The screen of the tube connects directly to B+. The output of the power supply will have a large electrolytic capacitor as the output filter capacitor. This capacitor provides a low impedance path from B+ to ground as far as the audio signal is concerned. Therefore, B+ is effectively at ground as far as the signal is concerned. Hence the bypass capacitor C_3 (which connects from the plate to the screen of the tube) effectively bypasses the high-frequency signal to ground.

In some receivers you will find C_3 connected directly between the plate of the tube and ground. The disadvantage of this arrangement is that C_3 must then be capable of withstanding the high dc plate voltage applied to the tube. By using the circuit shown in Fig. 10 and connecting C_3 between the plate and screen of the tube, the only dc voltage the capacitor must be able to withstand is the voltage drop across the primary winding of T_1. This voltage is usually nominal (somewhat less than 10 volts) so that C_3 does not have a high dc potential placed across it.

Sometimes you will see a triode tube used as the power output tube. A triode tube has the advantage over a pentode or a beam power tube, in that it usually produces less distortion. However, the disadvantage of the triode tube is that it requires a very high driving power. The power gain in a triode tube is relatively low compared to that of a beam power or a pentode tube. As a result, triode tubes have in general disappeared as power amplifiers in favor of beam power and pentode tubes.

TRANSISTOR CIRCUITS

A schematic diagram of a single-ended Class A amplifier using a PNP

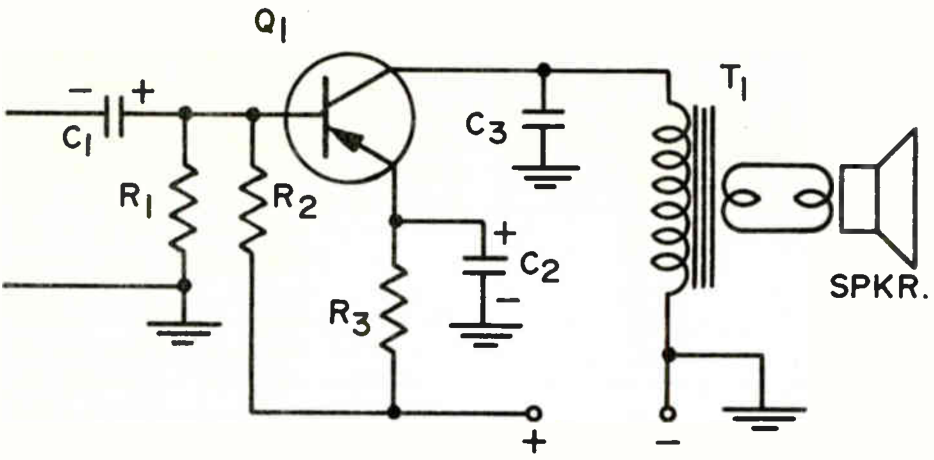

Fig. 11. Schematic diagram of single-ended Class A amplifier using a PNP transistor.

transistor is shown in Fig. 11. Notice that, in many respects, this circuit is similar to the vacuum tube circuit shown in Fig. 10.

The circuit we have shown in Fig. 11 is a common-emitter circuit and the output transformer is connected in the collector circuit. Again, the output transformer is an impedance-matching device. Its purpose is to match the speaker impedance to the output impedance of the transistor. Notice that capacitor C_2 is an electrolytic capacitor. The value of R_3 is comparatively low, so in order to hold the emitter at signal ground potential for all signal frequencies, the capacitor must be large. As in the case of a vacuum-tube circuit there will be some low frequency where the reactance of this capacitor becomes appreciable and reduces the gain of the amplifier at that frequency.

The input coupling capacitor C_1 (in the circuit shown) is an electrolytic capacitor. Again, remember that an electrolytic is required in the input of the stage because the input resistance of the transistor is very low and unless a large capacitor is used, there will be considerable loss in gain at low frequencies.

Once again, C_3 is a bypass capacitor. Its purpose is the same as that of the plate bypass capacitor in Fig. 10. It is used to prevent oscillation in the collector circuit and to provide a low-impedance path from the collector to ground for high-frequency signals in the collector circuit.

In a Class A stage of this type, the emitter-base junction is biased so that the transistor operates approximately in the midpoint of its characteristic curve. The bias is adjusted so that the signal does not overcome the emitter-base forward bias at any time and the current flow from the emitter to the collector is never cut off.

Transistor power amplifiers of this type are quite widely used in automobile receivers. In most automobiles the negative side of the battery is grounded. This means that the collector of the transistor is almost at ground potential. It is at ground potential less the voltage

Fig. 12. A power transistor.

drop across the primary of T_1. As a result, very little insulation is required between the collector and the receiver chassis. Power transistors resemble the transistor shown in Fig. 12. They are usually bolted to the chassis to provide a heat sink, or a means of getting rid of the heat dissipated by the transistor. Very little insulation is required between the transistor case and the chassis in a circuit of this type because there is very little voltage between the chassis and the collector. In most power transistors, the collector connects directly to the case of the transistor; therefore, the circuit provides a simple way of getting rid of the heat developed in the transistor and at the same time keeps the insulation requirements between the transistor case or collector to a minimum.

Of course, in a circuit of this type NPN transistors can be used as well as PNP transistors. For that matter, in automobile receivers where the battery voltage is only 12 volts, it is comparatively simple to insulate NPN transistor collectors from the chassis so that there will be no voltage breakdown, and at the same time provide adequate heat dissipation from the transistor.

Single-ended transistor amplifiers are also used in radio and television receivers that are operated from the power line. However, in portable-type equipment that operates from a dry cell-type battery, it is more economical to use push-pull transistors in Class B circuits. You will see this later.

SUMMARY

Class A power amplifiers are important because they are used in all types of equipment, especially in radio and television receivers. The power amplifier is a stage that converts the amplified signal to a signal with sufficient power to drive a loudspeaker. It consists of a tube or transistor, the output transformer, and the loudspeaker. The loudspeaker is the load; the output transformer is designed to match the speaker impedance to the output impedance of the tube or transistor.

You should be sure that you understand what a Class A power amplifier is and what it is supposed to do. If you go into radio and TV service work, you will run into an amplifier of this type in almost every radio or television set you will repair. If you plan to be a technician in a broadcast station you will find Class A power amplifiers in both radio and television equipment. If you intend to go into industrial electronics, you may be in a plant where a public address system is used. The chances are that you will find Class A amplifiers in this equipment. Regardless of what type of electronics work you do, you will encounter this type of amplifier.

SELF-TEST QUESTIONS

(o) What is the purpose of a power amplifier in a radio receiver?

(p) What type of tube can you expect to find in the power amplifier stage of most modern radio and television receivers?

(q) What is the purpose of the bypass capacitor used in the plate circuit of power amplifier tube circuits?

(r) In a circuit such as the one shown in Fig. 10, how can low-frequency distortion due to the reactance of the cathode bypass capacitor be kept to a minimum?

(s) What is the advantage of using a PNP transistor power amplifier (such as in Fig. 11) in an automobile receiver?

(t) Are you likely to find a single-ended or a push-pull power output stage in portable receivers which operate from batteries?

Push-Pull Power Amplifiers

In many applications it is impossible or at least uneconomical to try to obtain the required power from a single-ended stage. In such cases a double-ended power amplifier called a push-pull amplifier is used. A push-pull amplifier is particularly useful because it generates no second-harmonic distortion. Because of the circuit arrangement, any second-harmonic distortion produced is cancelled within the stage itself. Second-harmonic distortion is a signal having a frequency equal to twice the frequency of the signal to be amplified. Due to the curve in the characteristic curve of both tubes and transistors, single-ended stages produce a certain amount of second-harmonic distortion. However, in push-pull amplifiers, any second-harmonic distortion that is produced will be cancelled in the stage itself.

Push-pull stages may use either tubes or transistors, and you will study both types. Also, push-pull stages may be operated as Class A amplifiers or as Class B amplifiers. Often, you will find push-pull pentode or beam power stages operated as Class AB amplifiers. We will study and review some of the conditions of these various types of operations.

CLASS A AMPLIFIERS

A typical Class A push-pull amplifier using beam power tubes is shown in Fig. 13. Transformer T_1 can be a step-up transformer to provide additional drive between the grid and cathode of each tube. Notice that the cathode bias resistor R_1 is not bypassed. A bypass capacitor is not necessary because the current flowing through this resistor remains essentially constant. When the input signal drives the grid of V_1 in a positive direction so that the current flow through this tube increases, the signal will at the same time drive the grid of V_2 in a negative direction so that the current through that tube decreases. If the tubes are operated on the linear portion of their characteristic curves, the increase in plate current in V_1 should be offset by the decrease in plate current in V_2.

C_1 and C_2 serve as plate bypass capacitors for the two tubes. These capacitors prevent high-frequency oscillations which might cause the tubes to draw excessive current and burn out the primary of the output transformer.

Notice that the B+ for the screen of the tubes is obtained from the output filter capacitor. The B+ at this point will receive maximum filtering so that it is essentially pure dc. At the same time, the center tap of the output transformer, T_2, through which plate voltage is supplied to the two tubes, connects to the input filter capacitor. The dc voltage at this point will be somewhat higher than the voltage at the output filter capacitor due to any voltage drop that might occur in the filter choke or filter resistor used in the power supply. In addition, there will be considerably more hum voltage present at this point. At first, you might think that this would cause hum in the output. However, there are two factors which prevent hum in a circuit of this type. First, any hum current would flow through the two halves of the output transformer

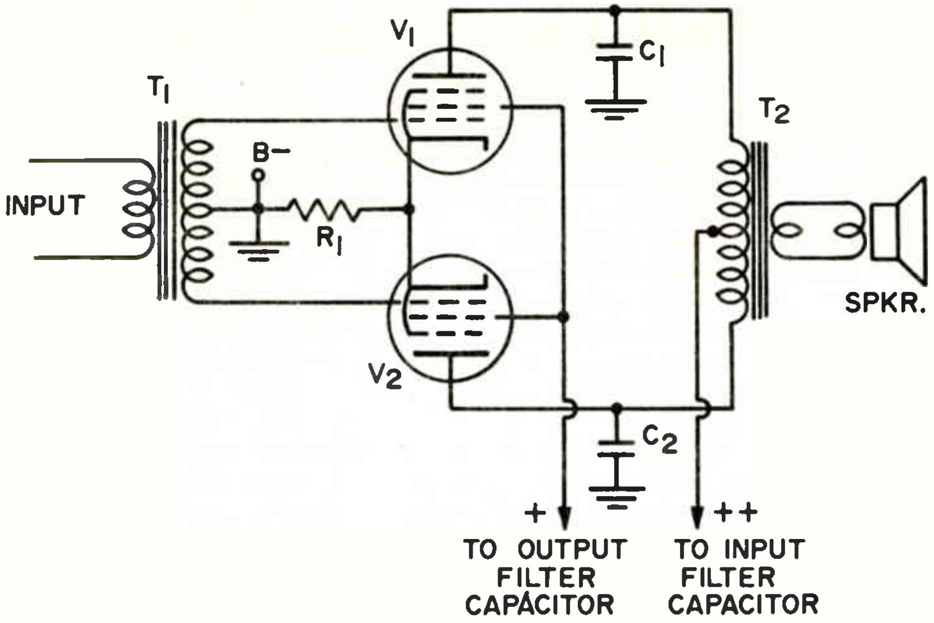

Fig. 13. Class A push-pull beam power tubes.

T_2 in opposite directions and hence tend to cancel. In addition, if there is some hum voltage on the plates of the two output tubes, remember that in pentodes and in beam power tubes the plate current depends very little on the plate voltage. It is determined primarily by the grid and screen voltages. Therefore, if there is some variation in the plate voltage on the tubes due to hum, this will not cause any appreciable change in plate current. Hence, the current flowing through the primary of T_2 remains essentially constant, and no hum will be fed to the speaker.

A push-pull Class A power amplifier using NPN transistors is shown in Fig. 14. Notice that, in many ways,

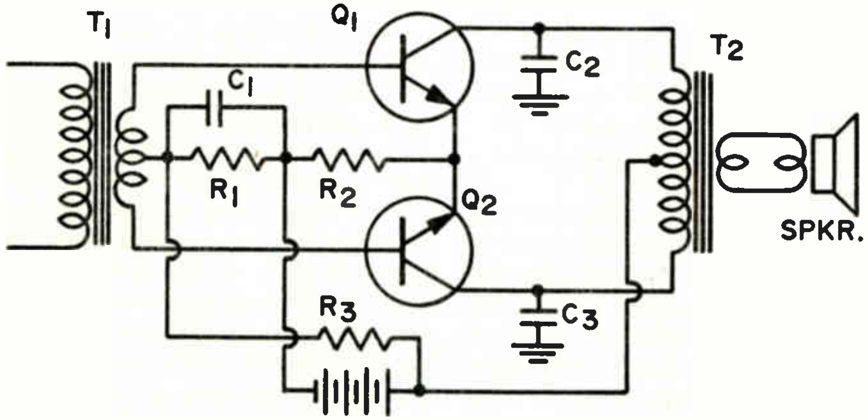

Fig. 14. Class A push-pull NPN transistors.

the circuit is similar to the vacuum-tube circuit in Fig. 13. The transformer T_1 is a step-down transformer; you will remember that the input resistance (or impedance, as it's more correctly called when referring to a signal) of transistors in a common-emitter circuit is quite low. Thus, T_1 serves as a matching device. Forward bias for the emitter-base junction is obtained by means of a voltage-divider network made up of R_1 and R_3 connected across the battery.

Resistor R_2, connected between the negative side of the battery and the emitter, is for bias stabilization purposes. In the event that the current through the transistor starts to increase due to a temperature rise in either transistor, the current through R_2 will increase and reduce the bias to hold the current through the transistors essentially constant.

Capacitors C_2 and C_3 are bypass capacitors that are used to prevent high-frequency oscillation in the output circuit. In some circuits the capacitors will be connected as shown, while in others a single capacitor connected directly between the two collectors may be used.

For simplicity, we have represented the power supply in the circuit as a battery. Of course, in a portable receiver or in an automobile receiver the actual power source will be a battery. However, in equipment designed for use in the home (where it will be operated from a power line) a power supply will replace the battery. The power supply will use a rectifier and a filter circuit similar to those you have already studied. It might also have a step-down transformer if the transistors are of the low-voltage type. However, many transistors are designed for high-voltage operation and equipment using this type of transistor will not require a transformer in the power supply.

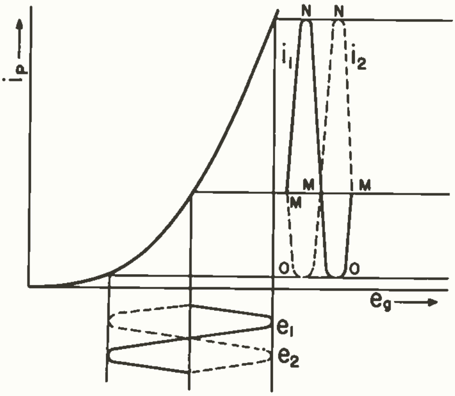

Fig. 15. When the operating point is on the lower bend of the tube characteristic curve, the plate current pulses i_1 and i_2 will be distorted.

Distortion Cancellation.

We mentioned previously that second-harmonic distortion generated within a push-pull amplifier is cancelled in the stage. Let's see how this distortion is produced and how it is cancelled.

First, we'll consider the beam power circuit shown in Fig. 13. Remember that the characteristic curve of a tube is not a straight line -- it is curved something like the line shown in Fig. 15. If the tube is operated on the bent portion of the curve shown in Fig. 15, distortion will be introduced.

Referring back to Fig. 13, let's consider the input signal across the primary of T_1 as "e" and in Fig. 15 consider the signals across the two halves of the secondary as e_1 and e_2. The plate current flowing through V_1 will be referred to as i_1 and the plate current flowing through V_2 as i_2. Let's look first at the signal e_1

applied to the tube V_1 -- this is represented in Fig. 15 as the solid line. When e_1 swings in a positive direction, i_1 increases as shown; when e_1 swings in a negative direction, then i_1 decreases as shown.

Notice, however, that the waveshape for the plate current is not equal in amplitude on the two sides of the zero axis -- that is, the alternation M-N-M is greater than the alternation M-O-M. This indicates that the stage has added second harmonics as well as other even harmonics to the original fundamental sine wave. In other words, it has added distortion (signals that were not present in the original signal).

At the same time, the other tube is getting the grid signal e_2, represented by the dotted line in Fig. 15. Notice also that the plate current i_2 is distorted on the M-O-M alternation. However, the plate current alternation of i_1 that is distorted occurs at the same moment as the portion of i_2 that is not distorted, and vice versa. This is due to the fact that e_1 and e_2 are 180° out-of-phase (when one is going positive, the other is going negative).

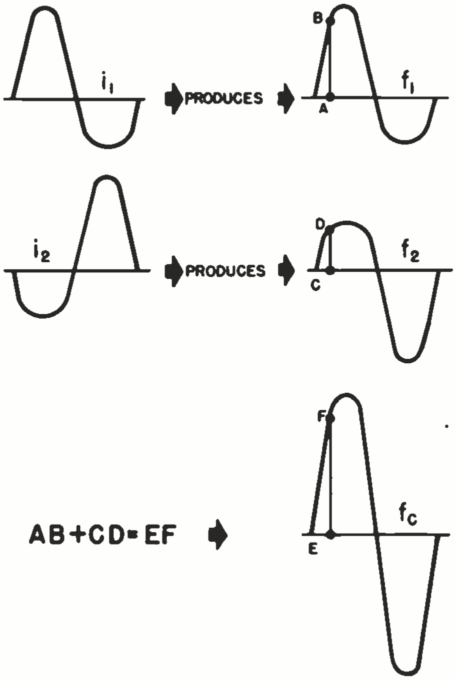

Fig. 16. The even-harmonic distortion cancellation occurs because of the manner in which the fluxes add in the output transformer.

In a transistor circuit such as is shown in Fig. 14, essentially the same thing happens. When the collector current of Q_1 is increasing, the collector current in Q_2 is decreasing. Similarly, when the collector current in Q_1 is decreasing, the collector current in Q_2 is increasing. Thus, if we have distortion in one-half of the output waveform produced by either transistor, we have exactly the same thing we have in the vacuum-tube stage, represented graphically in Fig. 15.

Now let's examine the action occurring in T_2 when the plate current of the two tubes (shown in Fig. 13) or the collector current of the two transistors (shown in Fig. 14) flows through the primary winding. This is shown in Fig. 16. Although the currents i_1 and i_2 are 180° out-of-phase, they now flow in opposite directions through the two halves of the primary T_2.

If i_1 produces flux f_1 and i_2 produces flux f_2 (as shown in Fig. 16), the fact that i_2 is flowing through the transformer in a direction opposite from that of i_1 means that flux f_2 will add to flux f_1, as if the two were being produced by a single current flowing through the entire primary winding. When f_1 and f_2 (in Fig. 16) are added, the resultant flux (f_c) is not distorted.

Because the resultant flux f_c is

not distorted even though the flux produced by the individual tubes or transistors is distorted, a push-pull amplifier will cancel out all even harmonics produced within the stage. In other words, if some second and fourth harmonic distortion is produced within the stage, it will be cancelled out in the stage because of the way in which the signals are recombined in the output transformer. This applies only to even-order harmonics produced within the stage because of a non-linear tube or transistor characteristic. A push-pull amplifier will not cancel even-order harmonics fed to it in the input, nor will it cancel out odd-order harmonics such as the third and fifth harmonics generated within the stage.

Push-pull amplifiers are not entirely distortion-free because a certain amount of third, fifth and higher odd harmonics will be produced within the stage. These harmonics are not cancelled out by another stage. Therefore, the amount of third harmonic distortion in the stage is usually what limits the amount of power we can get out of the stage without excessive distortion. The more power we try to get out of the stage, chances are the more third harmonic distortion there will be produced.

CLASS B AMPLIFIERS

A Class B push-pull amplifier using beam power tubes is shown in Fig. 17. Notice that this circuit is almost identical to the circuit shown in Fig. 13. The only difference is that the bias for the tubes is obtained from a separate source rather than from a cathode bias resistor. In Class B operation the tubes are biased approximately at cut-off. You cannot have current flow in the cathode circuit to develop this bias if the tubes are at cut-off and therefore grid bias for the tubes must be obtained from another source. It is usually obtained by placing a resistor in the negative side of the power supply.

In the Class B amplifier with the tubes biased to cut-off, when the in-

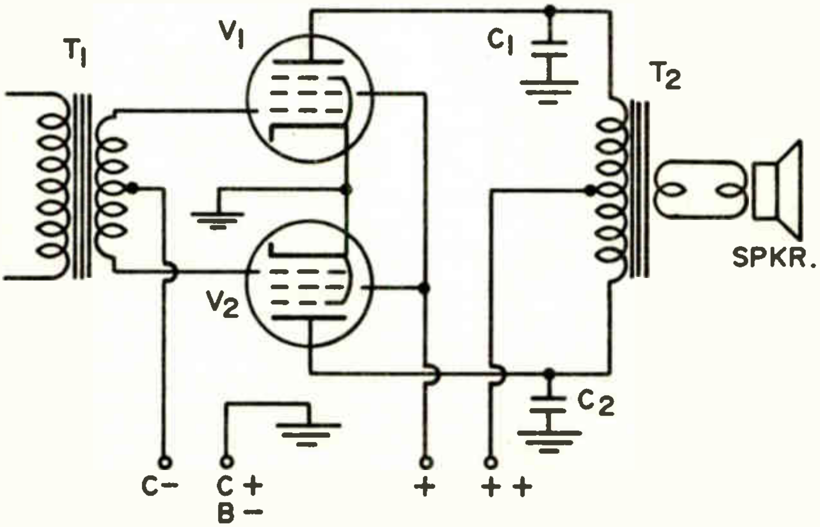

Fig. 17. Class B push-pull beam power tubes.

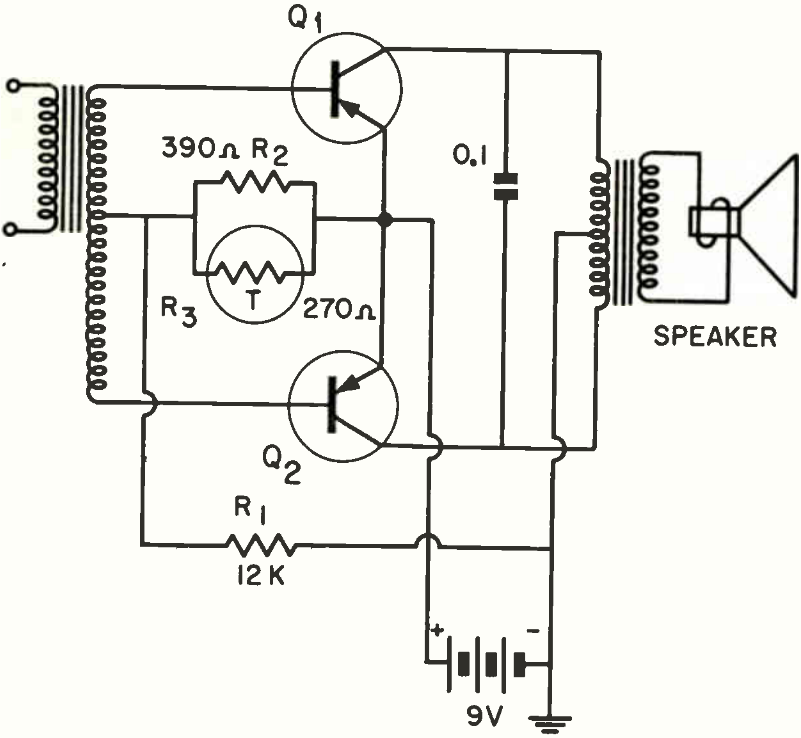

Fig. 18. Class B push-pull PNP transistors.

put signal swings the V_1 grid in a positive direction the tube will conduct. At the same time, the grid of V_2 will be driven in a negative direction so that no current will flow through V_2. During the next half-cycle, the opposite happens; the grid of V_2 is driven in a positive direction so that this tube conducts and no current flows through V_1.

Notice that we have indicated the plate and screen going to different voltage sources. As in the circuit shown in Fig. 13, the screen is returned to the output filter capacitor and the plate to the input filter capacitor in order to get the higher voltage on the plate.

Class B push-pull amplifiers using PNP transistors are shown in Fig. 18. Notice that the circuit is not too different from the tube circuit. The transistors are used in a common-emitter circuit. Bias is obtained by means of a voltage divider consisting of R_1 in series with the parallel combination of R_2 and R_3. The divider network is connected across the battery. When the input signal drives the base of Q_1 in a negative direction, Q_1 will conduct quite heavily. Holes will cross the emitter-base junction and flow over to the collector. At the same time as the base of Q_1 is driven in a negative direction, the base of Q_2 will be driven in a positive direction so that the base will be positive with respect to the emitter. Thus there will be reverse bias across the emitter-base junction of this transistor, and no current will flow through it. During the next half-cycle when the signal is reversed, the base of Q_1 will be driven in a positive direction so that a reverse bias will be placed across the emitter-base junction of this transistor and hence no current will flow through it. The base of Q_2 will be driven in a negative direction, increasing the forward bias so that the current flow through the transistor is increased. The number of holes crossing the emitter-base junction increases, and therefore the number of holes reaching the collector will increase.

The resistor R_3 in the emitter circuit is for bias stabilization purposes. This resistor is a thermistor. If the temperature is high, the resistance of R_3 will go down. This will reduce the forward bias across the emitter-base junction of the transistors and prevent the current from becoming excessive.

CLASS AB AMPLIFIERS

Quite frequently, vacuum tubes are not operated as Class B power amplifiers, but rather as Class AB power amplifiers. This is particularly true of amplifiers using beam power tubes. You can obtain almost as much power out of a Class AB vacuum tube as you can from the Class B circuit and the distortion is usually somewhat less with the Class AB operation. You will remember that for Class AB operation, bias on the tubes is about halfway between the bias used for Class A operation and the bias used for Class B operation. If the grids are driven positive at any time during the input cycle, we refer to the operation as Class AB_2 operation. If the grids are not driven positive then it is referred to as Class AB_1 operation.

When the power amplifier is operated as a Class AB_2 amplifier or a Class B amplifier where the grids of the tube are actually driven positive, the tubes consume power in the grid circuit. In an application of this type, the input transformer must be a step-down transformer in order to provide the power needed in the grid circuit. In addition, instead of using a voltage amplifier in the preceding stage, a power amplifier stage is required. In other words, in a circuit such as is shown in Fig. 17, the stage driving the push-pull Class B power amplifiers would probably be a single-ended Class A power amplifier. The Class A power amplifier produces the power required in the grid circuit of the two tubes. In Class A or Class AB_1 operation where the grids are not driven positive, the tubes do not require grid power and can be driven by a voltage amplifier stage.

SELF-TEST QUESTIONS

(u) In Fig. 13, why is the cathode resistor R_1 not bypassed?

(v) In Fig. 13, what purpose do C_1 and C_2 serve?

(w) In Fig. 14, is T_1 a step-up or a step-down transformer?

(x) What is one of the primary advantages of a push-pull type of power amplifier circuit?

(y) What is the difference between the Class A power amplifier in Fig. 13 and the Class B power amplifiers in Fig. 17?

(z) In Fig. 18, how are the transistors biased?

Reducing Distortion

Distortion is one of the most serious problems in low-frequency amplifiers. There are three kinds of distortion with which we must contend: amplitude distortion, frequency distortion, and inter-modulation distortion.

Amplitude Distortion.

Amplitude distortion results from the creation of irregularities in amplifying the signal. For example, one-half of a sine wave does not receive the same amplification as the other half, and harmonic distortion is produced. This means that signals that are multiples of the original signal frequency are produced. If the signal has twice the frequency of the original signal, it is called second harmonic distortion; if the signal is three times the frequency of the original signal, it is called a third harmonic distortion, and so on.

A small amount of distortion of this type is hardly noticeable, but the quality of the amplified signal usually suffers if you get a certain amount of second harmonic distortion plus some third (and higher) harmonic distortion.

Sometimes, in amplifying a sine wave, a small pip or irregularity may appear on the sine wave that was not present in the original signal. This type of distortion is also called amplitude distortion.

Frequency Distortion.

You already know that the gain of an amplifier falls off at low frequencies due to the reactance of the coupling capacitor used between the stages of an amplifier. Thus, low-frequency signals in some amplifiers do not receive the same amount of amplification as the middle-frequency signals receive. Similarly, at some high frequency, the various capacities in the circuit begin to reduce the gain of the amplifier at high frequencies so that high-frequency signals do not receive the same amount of amplification as middle-frequency signals receive. This failure to amplify signals at all frequencies equally is known as frequency distortion.

Inter-Modulation Distortion.

If an amplifier is not operated on the linear portion of its characteristic curve, mixing of two or more signals in the amplifier sometimes occurs. For example, suppose that two signals are fed to an amplifier at the same time. This might happen when an amplifier is amplifying musical notes of two different frequencies. If the two signal frequencies beat together to produce new signals equal to the sum and difference of the original signal frequencies, we have what is called inter-modulation distortion. In this case, the two signals have mixed together.

Inter-modulation distortion can be kept to a minimum by operating the amplifier on the linear portion of its characteristic curve and by avoiding operation of the amplifier at or near its maximum amplification capabilities.

There are several methods used to keep distortion to a minimum. One of these, of course, is careful design; another is making sure that the tube or transistor used in the amplifier is operated as it should be. This, however, is not enough to get what we would call good high-fidelity reproduction, although it is good enough for most table-model radio receivers (where we do not expect extremely high-quality output) and for television receivers (where we are primarily interested in sound to accompany the picture). In quality sound-reproducing equipment (high-fidelity or stereo, for example), on the other hand, steps must be taken to keep distortion as low as possible. One of the simplest steps in reducing distortion is the use of inverse feedback.

INVERSE FEEDBACK

Fig. 19 illustrates two simple examples of inverse feedback. The circuit at A shows a vacuum tube; the circuit at B, a transistor.

Looking first at the vacuum-tube circuit, we see that it is exactly the same as the circuit you studied previously, but in this case the bias resistor (R_2) in the cathode of the circuit of the tube is not bypassed.

The purpose of the cathode bypass capacitor is to bypass signals around the cathode resistor, R_2. We pointed out previously that all capacitors have a certain reactance, and that at low frequencies this capacitor may not be a good bypass. As a result, there will be some attenuation of low-frequency signals. By completely eliminating the capacitor, we can eliminate the problem. Now all signals will receive some reduction in amplification because there is a

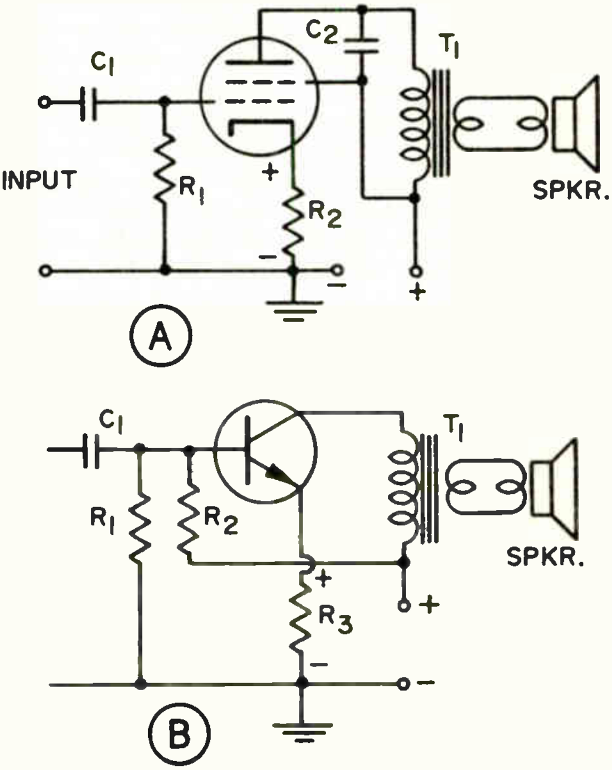

Fig. 19. Simple inverse feedback circuits.

certain amount of feedback in the circuit.

Let's consider what happens when a signal drives the grid of a tube in a positive direction. This causes the current flow through the tube to increase; hence the voltage drop across R_2 (which has the polarity shown on the diagram) increases. Thus the cathode swings in a positive direction. The signal voltage developed across R_2 is subtracted from the grid voltage. We then have a certain amount of feedback; in other words, the signal from the output circuit is fed back into the input circuit. We call this feedback "inverse" because the signal subtracts from the input signal.

In the transistor circuit shown in Fig. 19B, the resistor R_3 is put in the emitter circuit for temperature stabilization. It is usually bypassed, but the bypass capacitor acts in exactly the same way as the cathode-bypass capacitor in the tube circuit. At low frequencies, the capacitor is not an effective bypass. By eliminating the capacitor a certain amount of inverse feedback is introduced into the circuit. When the input signal drives the base in a positive direction, the forward bias across the emitter-base junction increases and the current flow through the transistor increases. This causes the voltage across R_3 to increase and the increase in voltage subtracts from the positive base voltage, thus reducing the net base-emitter signal voltage.

The feedback signal will be developed at all signal frequencies and will tend to make the gain of the amplifier more constant over a wider frequency range. You can see why this is so if you consider that at some frequency the signal reaching the amplifier has a higher amplitude than at other frequencies. This signal in the case of the circuit at A will cause a higher cathode current through the tube. Hence the voltage across R_2 will be higher than at other frequencies and will tend to reduce the input signal more than at other frequencies. Similarly, if the signal applied to the base is greater at some particular frequency, it will tend to develop a higher feedback signal across R_3. This, in turn, will tend to reduce it more, keeping it closer to the amplitude of the other signal frequencies.

We sometimes call this type of feedback "degeneration". Degeneration and inverse feedback are essentially the same thing. When the signal fed from the output circuit back to the input circuit reduces the input signal, we say this is degenerative feedback or inverse feedback. When the signal fed from the output circuit back to the input circuit adds to or aids the input signal, we call it regenerative feedback. Regenerative feedback is never used to improve the response of an amplifier.

The example of inverse feedback shown in Fig. 19 is in both cases contained within a single stage. Inverse feedback can be used over more than one stage as shown in the example in Fig. 20. Here a signal is fed from the plate of the output tube back to the cathode of the voltage amplifier tube.

In the circuit shown in Fig. 20, when the input signal drives the grid of V_1 in a positive direction, a negative-going signal will be developed in the plate circuit. This signal is fed to the grid of V_2 through the capacitor C_3 and this in turn causes a positive-going signal in the output circuit of V_2. The positive-going

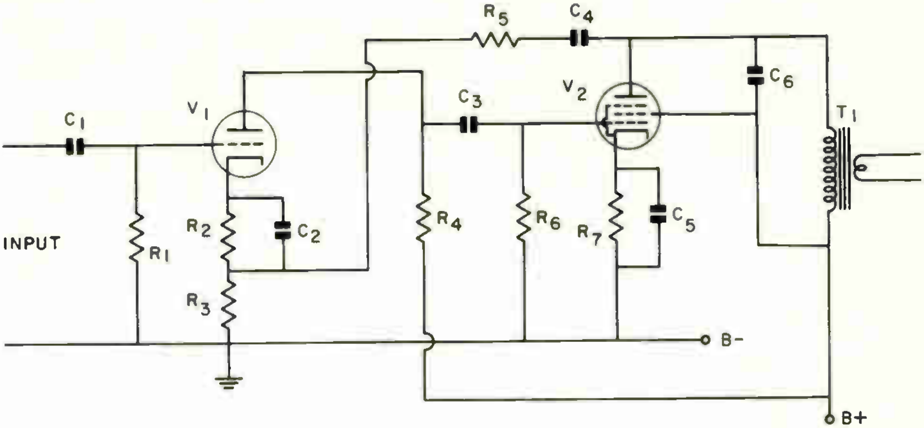

Fig. 20. Inverse feedback from the plate of the power output tube to the cathode of the voltage amplifier tube.

signal is fed through C_4 and R_5 back into the cathode circuit of V_1 where it subtracts from the input signal fed to V_1. The advantage of two-stage feedback of this type is that it tends to equalize the gain of the amplifier over both stages rather than in just a single stage as in the circuits shown in Fig. 19.

PHASE INVERTERS

One of the causes of distortion in push-pull power amplifiers (such as in Fig. 13) is the input transformer. Transformers that respond equally to a wide range of frequencies are difficult and expensive to manufacture. The transformer in this circuit can be eliminated by means of a phase inverter stage as shown in Fig. 21.

In this circuit the input signal is applied between the grid and cathode of V_{1A}. It is amplified by this tube and the signal phase is inverted. The signal is fed through C_3 to the grid

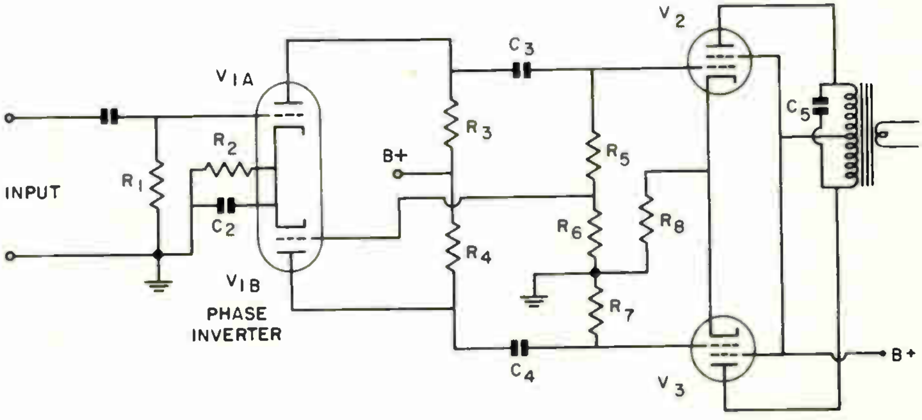

Fig. 21. A typical circuit using a phase inverter to drive one stage of a push-pull amplifier.

of V_2. Meanwhile, the amplified signal is divided by the resistors R_5 and R_6. Usually, R_5 is considerably larger than R_6 so that only a small part of the amplified signal is taken and fed back to the grid of V_{1B}, the phase inverter stage. Remember that this signal will be in phase with the signal fed to the grid of V_2. The signal is amplified by V_{1B}; its phase is inverted and then fed through C_4 to the grid of V_3. Thus V_2 and V_3 are driven by signals 180° out-of-phase.

If the ratio of R_5 and R_6 are selected correctly, the amplified signal fed to the grid of V_3 will be equal to the amplified signal fed to the grid of V_2. This type of circuit provides the two signals equal and 180° out-of-phase to drive the push-pull power amplifier. At the same time, better frequency response can be obtained with this type of circuit than with the circuit shown in Fig. 13 using an input transformer.

A circuit similar to the one shown in Fig. 21 could be used with transistor push-pull stages, but here the input transformer is primarily an impedance-matching device and usually there is more to be gained by using the input transformer than by attempting to use the phase-inverter type of stage found in push-pull vacuum-tube amplifiers. There are other things that can be done with transistor circuits to get improved results that cannot be done with vacuum-tube circuits. We will look at these circuits now.

TRANSISTOR CIRCUITS

A two-transistor amplifier which uses a PNP transistor and an NPN transistor is shown in Fig. 22. This amplifier makes use of the characteristics of the two different transistors to eliminate the coupling capacitor usually found between amplifier stages, and in so doing also eliminates distortion due to the capacitor.

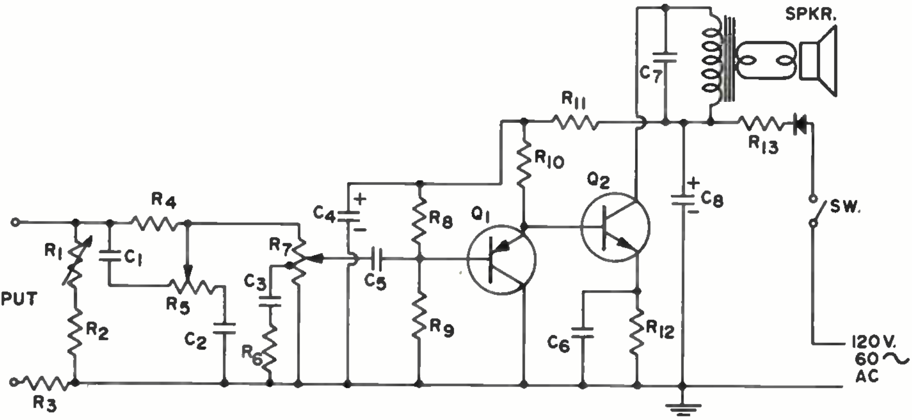

Fig. 22. Two-stage transistor amplifier.

In the circuit shown, the input impedance is controlled at high frequencies by R_5. C_1 and C_2 have a low reactance at middle and high frequencies, so the total impedance across the input at high frequencies will be equal to the resistance of R_5. At low frequencies, R_1 varies the input impedance. By varying the setting of R_1, the input impedance (and hence the amplitude of any low-frequency input signal) can be varied. Thus R_1 serves as a bass or low-frequency tone control. R_4 is in the input circuit between the input and the volume control. It can be bypassed at high frequencies by the setting of R_5. When the sliding contact is up towards C_1, C_1 provides an effective bypass around R_4 at high frequencies. When the sliding contact is down at the other end, R_4 and R_5 are essentially in parallel at high frequencies, and this tends to reduce the amplitude of the high-frequency signals. Thus, R_5 serves as a high-frequency tone control, which is usually called a treble control.

R_7 is the volume control. Notice that this control has a tap on it, and that C_3 and R_6 are connected between the tap and ground. This type of circuit is referred to as automatic bass compensation. When you turn the volume control to the low-volume position, the low-frequency sounds appear weaker than the high-frequency sounds. The higher-frequency signals are attenuated by means of C_3 and R_6, so that there is a tendency to equalize the loudness of the high-frequency and low-frequency signals. Actually, the low-frequency signals are given greater amplification to compensate for the fact that they are less noticeable at low volume levels. The transistor Q_1 is used in a common collector circuit. The input signal is fed to the base through C_5. The output is taken across the emitter resistor (R_{10}) and is fed directly to the base of Q_2. Q_2 is a power transistor which is used in a common-emitter circuit.

The two-stage amplifier is designed to operate directly from a 120-volt power line. Notice that a half-wave rectifier circuit using a silicon rectifier is shown. Resistor R_{13} is a series resistor to limit the charging current through the rectifier when the equipment is turned on. C_8 is the input filter capacitor; C_4, the output filter capacitor. R_{11} is the filter resistor. The supply voltage applied to the collector of Q_2 is not filtered as well as the voltage fed to Q_1. The voltage fed to Q_2 does not require the filtering because if there is hum voltage present with the dc, it does not receive any amplification. However, any hum voltage on the dc applied to Q_1 will be amplified and will result in an objectionable hum in the output.

Another transistor circuit of interest is the one shown in Fig. 23. This circuit is referred to as a complementary-symmetry push-pull amplifier. Here an NPN transistor and a PNP transistor are used. When the input signal drives the base of Q_1 in a positive direction, the current through Q_1 will decrease because this transistor is a PNP transistor and the positive voltage applied to the base of the transistor tends to decrease the forward bias applied to it. At the same time, the positive input signal is fed to the base of Q_2 and this increases the emitter-base forward bias and causes the current through this transistor to increase. This current is represented by i_2 and flows through the output transformer primary in the direction shown. In the next half-cycle, when the signal swings negative, this will subtract from the forward bias across Q_2, reducing the

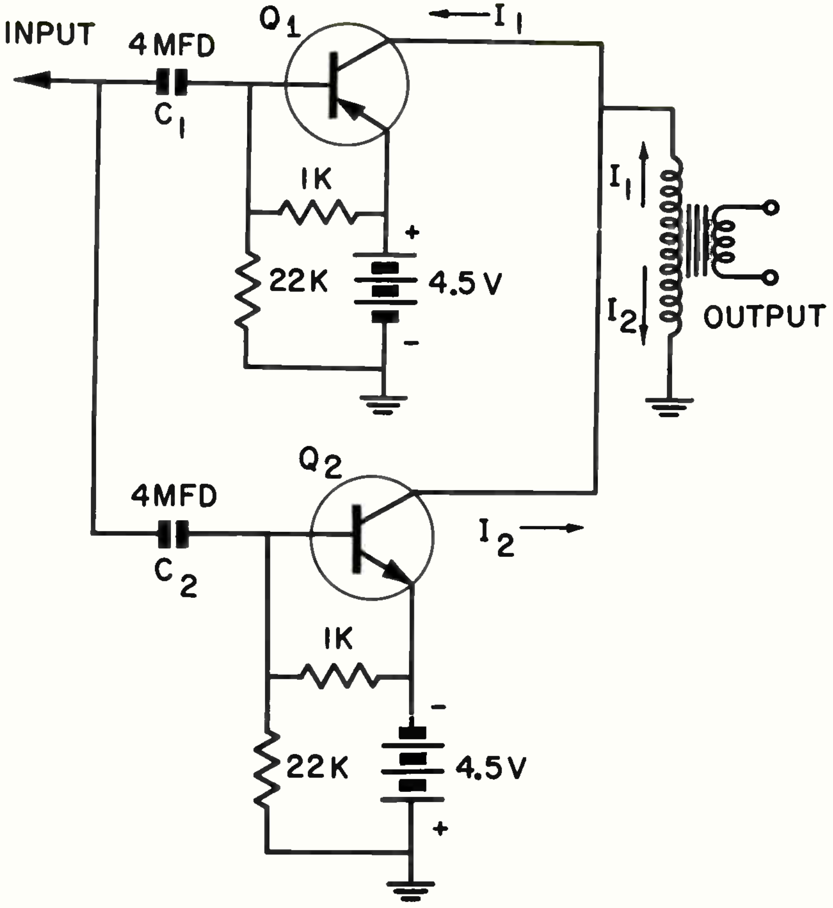

Fig. 23. Complementary symmetry push-pull amplifier.

current flow through it, and increase the forward bias across the emitter-base of Q_1, causing the hole flow through it to increase. The increase in hole flow through the transistor results in an increase in current flow i_1 through the primary of the output transformer in the direction shown.

If the transistors shown in Fig. 23 are balanced and biased essentially so that they are cut off without any signal flow, there will be no current flow through the primary of the transformer until a signal is applied. Then the current will flow through the transformer; the direction of flow will depend upon whether the signal is positive-going or negative-going. During one half-cycle the current will flow through the primary of the output transformer in one direction and during the other half-cycle it will flow through the primary of the transformer in the opposite direction.

Notice that this type of circuit eliminates the input transformer,

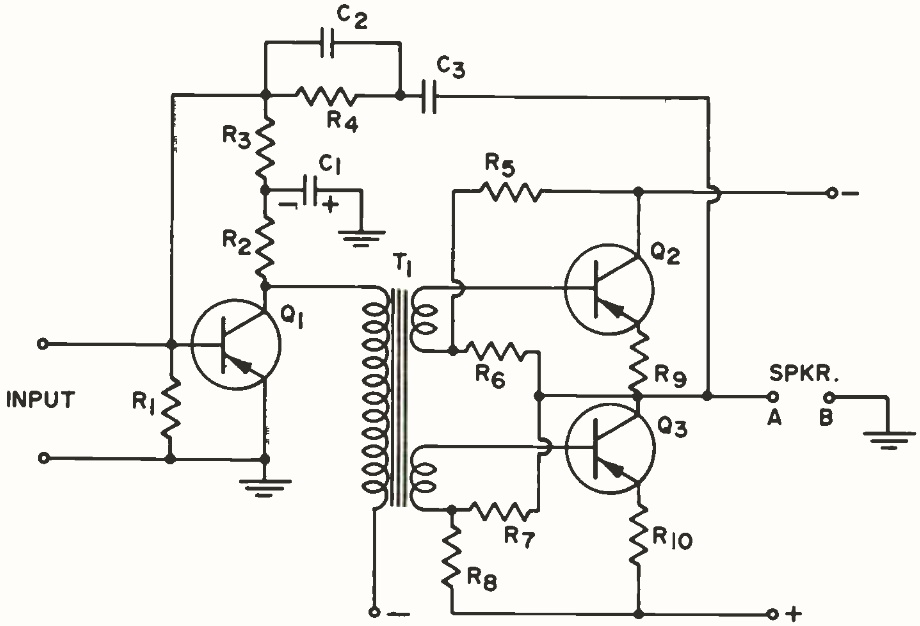

Fig. 24. Three transistor amplifiers where there is no output transformer.

yet we still have a push-pull power amplifier. In a circuit designed for power line operation, batteries would not be used and a single power supply capable of supplying the required positive and negative voltages would be used.

Another transistor circuit of interest is shown in Fig. 24. In this circuit the need for an output transformer has been eliminated. Notice that a negative voltage has been supplied to the collector of Q_2 and a positive voltage to the emitter of Q_3 through R_{10}. The negative voltage has the same value as the positive voltage with respect to ground. The resistors R_5 plus R_6 are equal in value to resistors R_7 and R_8 so that the junction of R_6 and R_7 will be at ground potential. Similarly, R_{10} is equal to R_9, and Q_2 and Q_3 are similar transistors so that there is an equal voltage drop across the emitter resistor and transistor in each case. The junction of the collector of Q_3 and resistor R_9 are also at ground potential. The junction of R_6 and R_7 and the collector of Q_3 and R_9 are connected together at terminal A. The speaker is connected between terminals A and B.

With no signal the transistors are biased essentially at cut-off so that there is little or no current flow through the transistors or through the speaker. When a signal is applied to the input circuit, it is amplified by Q_1 and fed to the transformer T_1. For example, suppose that the input signal drives the base of Q_1 in a positive direction. Since the transistor is a PNP transistor, this will reduce the forward bias across the emitter-base junction. This means that the number of holes reaching the collector will decrease and hence the current flowing through the primary of T_1 will decrease. The two secondary windings on T_1 are phased so that when this happens the voltage applied to the base of Q_3 will swing in a positive direction and the voltage applied to the base of Q_2 will swing in a negative direction. If Q_3 is already biased close to cutoff the positive voltage on the base will reduce the emitter-base junction forward bias still further so that if there is any current flowing through this transistor, it will drop even lower. On the other hand, the negative voltage applied to the base of Q_2 will increase the forward bias across the emitter-base junction. This will cause the number of holes crossing the junction to increase; the number of electrons flowing from the emitter of Q_2 through R_9 to terminal A and through the speaker to ground will also increase.

The current flowing through the speaker will develop a voltage drop across it so that the end connected to terminal A will be negative. This negative signal voltage will be fed through C_3 and the parallel combination of C_2 and R_4 back to the base of Q_1, where it will subtract from the input signal. Thus, this is an inverse feedback path.

When the signal swings in the opposite direction and drives the base of Q_1 in a negative direction the number of holes crossing the emitter-base junction will increase and hence the electron current through the primary of T_1 will increase. This will cause the base of Q_3 to swing in a negative direction. When this happens the number of holes crossing the emitter-base junction of Q_3 must increase. Therefore the number of electrons flowing from terminal B through the speaker to terminal A to the collector of Q_3 must increase. In flowing through the speaker in this direction, the electrons will develop a voltage so that terminal A is positive. This voltage is fed back to the input of Q_1 and will once again subtract from the input voltage.

The circuit is interesting in that the output transformer has been eliminated. The output transformer is one of the primary causes of distortion in low-frequency power amplifiers. Usually, there is more distortion developed in the output transformer than in the input transformer, because dc current flowing through the output transformer will be much higher than the dc current flowing through the input transformer. Also, there is more of a tendency to produce core saturation, which in turn produces more nonlinearity in the output transformer than in an input transformer.

A circuit of the type shown in Fig. 24 is not possible with vacuum tubes because of the high output impedance encountered in tubes. However, transistors are comparatively low-impedance devices, which makes this type of circuit practical.

SUMMARY

The circuits shown in this section of the lesson are all practical circuits. They are the type of voltage and power amplifiers you are likely to encounter in radio and television receivers and in high-fidelity and stereo equipment which you will be called upon to service. You should be familiar with the operation of these circuits so that when you come across them you will know how they work and be able to proceed to the cause of the trouble in a logical manner.

SELF-TEST QUESTIONS

(aa) What is distortion?

(ab) Name the three types of distortion.

(ac) What is inverse feedback?

(ad) In the circuit shown in Fig. 19, how does omitting the cathode bypass capacitor introduce inverse feedback?

(ae) In the circuit shown in Fig. 21, what is the purpose of the phase inverter stage?

(af) In Fig. 22, what purpose does R_1 serve?

(ag) In the circuit shown in Fig. 22, what purpose does R_5 serve?

(ah) In the circuit shown in Fig. 22, why is there a tap on the volume control on R_7? What purpose does this tap and the associated components serve?

(ai) In the circuit shown in Fig. 22, in what type of circuit is Q_1 used?

(aj) What is the primary advantage of the circuit shown in Fig. 24?

(ak) In Fig. 24, what purpose does the circuit serve which connects terminal A through C_3 and the parallel combination of C_2 and R_4 back to the base of Q_1?

ANSWERS TO SELF-TEST QUESTIONS

(a) R_1 is placed in the cathode circuit of V_1 to develop an operating bias for the tube. Current flowing from B minus through R_1 will develop a voltage having the polarity shown on the diagram. This makes the cathode positive with respect to ground. The grid of V_1 connects to ground through the generator and, since there will be no dc current flow through the grid circuit, there will be no voltage drop; therefore, the grid will be at dc ground potential. This will make the cathode positive with respect to the grid. In other words, the grid is negative with respect to the cathode.

(b) C_1 is a cathode bypass capacitor. Its purpose is to provide a low impedance path for the signal around the cathode bias resistor R_1. The value of C_1 is selected so that its reactance is much lower than the resistance of R_1 at the frequency of the signals to be amplified. Often, C_1 is an electrolytic capacitor; a large capacitor is required in this circuit because the resistance of R_1 is usually small and a large capacitor with a low reactance is required to bypass it effectively.

(c) In Fig. 1, the amplified signal voltage developed across R_2 will be 180° out-of-phase with the input signal voltage.

(d) No. The voltage drop across R_1 has the wrong polarity to provide a forward bias across the emitter-base junction of Q_1. The forward bias across the emitter-base junction is provided by the battery. The small current flowing through R_1 develops a voltage across this resistor having the polarity shown. This voltage subtracts from the battery voltage so that the net forward bias across the emitter-base junction is equal to the battery voltage less the voltage drop across R_1. Usually, the forward bias of only a few tenths of a volt is required across the emitter-base junction and R_1 is selected so that the base current flowing through it will develop a voltage drop, and when it is subtracted from the battery voltage the forward bias will be only a few tenths of a volt.

(e) No. The holes flow to the collector, where they are filled by electrons. These electrons come from the negative terminal of the battery and flow through R_2 to the collector. The movement of the holes is contained entirely within the transistor. In the external circuits, all current flow is electron flow.

(f) The forward bias placed across Q_1 makes the base negative and the emitter positive. When the input signal tends to swing the base in a positive direction it reduces the forward bias across the emitter-base junction. When this happens the number of holes crossing the junction decreases. When the number of holes crossing the emitter-base junction goes down, the number of holes reaching the collector will go down. This means that fewer electrons will flow through R_2 to fill the holes reaching the collector. When the number of electrons flowing through R_2 decreases, the voltage drop across R_2 will go down, so that the polarity of the collector end of R_2 will swing in a negative direction. In other words, the negative voltage on the collector of Q_1 will increase.

(g) In the circuit shown in Fig. 2, the value of C_3 is selected so that it will have a very low reactance over the frequency range of the signals to be amplified. Therefore, as far as the signal is concerned C_3 acts as a short circuit. In other words, the circuit functions as though there is a direct connection from both ends of R_2 to the end of R_3. The input resistance of Q_2 is equal to R_3 in parallel with the resistance across the emitter-base junction. The resistance across the emitter-base junction is comparatively low; therefore, the input resistance of Q_2 is low. The signal voltage developed in the collector circuit of Q_1 will depend upon the size of the load resistor. Thus, even though R_2 may be made large in order to develop a fairly high signal voltage, since the input resistance of the second stage is directly in parallel with this resistor it will pull the effective value of the collector load resistance down. As the net result, the gain of Q_1 is affected appreciably by the input resistance of the second stage, Q_2.

(h) The coupling capacitor C_3.

(i) The high frequency limit of the amplifiers is controlled primarily by the capacity in the output of the first stage and the input of the second stage. In Fig. 1 the output capacity is made up of the plate-to-ground capacity of V_1 plus wiring capacity and the grid-to-cathode capacity of V_2 plus wiring capacity. In Q_1 the output capacity of the transistor plus wiring capacity limits the frequency response along with the input capacity of Q_2 plus wiring capacity in this circuit.

(j) The early vacuum tubes were not capable of giving a very high gain. By means of a step-up transformer between stages the gain obtainable from the stage could be increased by the turns ratio of the transformer.

(k) The high gain available with modern vacuum tubes makes transformer coupling no longer necessary. In addition, R-C coupling is more economical and yields better frequency response.

(l) The transformer serves as an impedance-matching device. It matches the high output impedance of the first stage to the low input impedance of the second stage. Thus, maximum power transfer is possible and a higher voltage gain can be obtained.

(m) Modern transistors are relatively inexpensive. By using a three-stage R-C coupled voltage amplifier you can obtain as much gain as with a two-stage transformer coupled amplifier. The R-C coupled amplifier will be less expensive and also capable of better frequency response.

(n) You must obtain a replacement transformer having the same turns-ratio as the turns-ratio of the original transformer.

(o) The power amplifier in a radio receiver is designed to supply the power required to drive or operate the loudspeaker from the signal voltage applied to it.

(p) A beam power tube or a pentode tube. Triode tubes have been used as power amplifiers but they require considerable driving power. Therefore, it is not likely you will find a triode tube in modern equipment.

(q) The bypass capacitor in the plate circuit of a power amplifier is used to bypass the high-frequency audio signals and prevent high-frequency oscillation.

(r) Low-frequency distortion can be kept to a minimum by using a large value capacitor for C_2, the cathode bypass capacitor. This will reduce the frequency at which the reactance of the capacitor becomes large enough to stop acting as an effective bypass.

(s) The collector which is connected to the case of the transistor must dissipate a fair amount of heat. Since the collector is operated at almost ground potential, very little insulation is required between the collector and ground. Thus a good heat contact can be made between the collector and receiver chassis so that the chassis can aid in dissipating the heat from the transistor.

(t) You are more likely to find a push-pull output stage where the transistors are operated in a Class B circuit.

(u) The cathode bias resistor is not bypassed because the current through it remains essentially constant. Any increase in current through V_1 is compensated for by an equal decrease in current through V_2 and vice versa.

(v) C_1 and C_2 are plate bypass capacitors. They prevent high-frequency oscillation.

(w) T_1 is a step-down transformer. A step-down transformer is required to match the low input impedance of Q_1 and Q_2 to the high output impedance of the driver stage.

(x) In a push-pull power amplifier, even-order harmonics generated within the stage are cancelled within the stage so that the distortion is kept quite low.

(y) The circuits are practically identical except that a higher bias is used in Fig. 17 in order to bias the tube essentially at plate current cut-off. In addition, T_1 will be a step-down transformer in the circuit shown in Fig. 17, although it can be a step-up transformer in the circuit shown in Fig. 13.

(z) Forward-bias across the emitter-base junctions in the circuit shown in Fig. 18 is provided by the voltage divider consisting of R_1 in series with the parallel combination of R_2 and R_3. This will bias the base slightly negative with respect to the emitter.

(aa) Distortion is the introduction of a signal in the output that is not present in the input or the loss of a signal in the output that is present in the input.

(ab) Amplitude distortion, frequency distortion and intermodulation distortion.

(ac) Inverse feedback is a signal fed from the output of a circuit back to the input, with a polarity such that it subtracts from the input signal. With inverse feedback, the feedback signal reduces the amplitude of the input signal.

(ad) With the cathode bypass capacitor omitted, the signal current flowing through the tube will develop a voltage across R_2. Since this voltage has the same polarity as the grid voltage producing it, it reduces the net grid-to-cathode voltage. The voltage thus subtracts from the input voltage.

(ae) The phase inverter eliminates the need for an input transformer to the push-pull output stage. It takes part of the signal fed to V_2, one of the output stages, and inverts it so that it can be used to drive V_3.

(af) R_1 serves as a low-frequency tone control. This type of control is called a base control.

(ag) R_5 serves as a high-frequency tone control. It is usually called a treble control.

(ah) The tap on the volume control along with capacitor C_3 and R_6 form an automatic bass compensation circuit. At low volume levels, low-frequency sounds sound weaker than high-frequency sounds. To balance the relative loudness between the two, the high-frequency signals are bypassed through C_3 and R_6 so that the low-frequency signals receive greater amplification.

(ai) Q_1 is used in a common-collector circuit.

(aj) The elimination of the output transformer.

(ak) This circuit provides inverse feedback to improve the frequency response of the amplifier.

Lesson Questions

Be sure to number your Answer Sheet B202.

Place your Student Number on every Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time, or you may run out of lessons before new ones can reach you.

1. When considering the action of the coupling network at middle frequencies, why can we ignore the coupling capacitor C_3 in Figs. 1 and 2?

2. In Fig. 2, what percentage of the signal voltage appearing across R_2 will appear across R_3 at the low-frequency half-power point?

3. Why is more gain obtained from the two-stage transformer-coupled voltage amplifier shown in Fig. 9 than from the two-stage voltage amplifier circuit shown in Fig. 2?

4. If transformer coupling between transistor voltage amplifiers provides maximum gain, why is R-C coupling more frequently used?

5. What is the difference between a voltage amplifier and a power amplifier?

6. In Fig. 14, will the voltage drop across R_2 add to or subtract from the forward bias across the emitter-base junction of Q_1 and Q_2?

7. Why are push-pull Class B power amplifiers preferred over push-pull Class A power amplifiers or single-ended power amplifiers in transistor portable receivers?

8. What is the advantage of using inverse feedback in low-frequency voltage and power amplifier stages?

9. In the two-stage amplifier shown in Fig. 22, in what type of circuit are the transistors Q_1 and Q_2 used?

10. What will be the polarity of the voltage at terminal A, in the circuit in Fig. 24, when the input signal drives the base of Q_2 in a positive direction and the base of Q_3 in a negative direction?

CONVERSATIONALLY SPEAKING

Conversation is a give-and-take proposition, and listening is the "take" part. Talk only when you can say something of interest. Otherwise, remain silent. Let your silence be eloquent enough to show that you derive pleasure from listening--that you consider the words of your companion far more valuable than anything you could say. This kind of silence can make just as many friends as good conversation.

Talk about things which will interest and please your listeners. Their hobbies, their work, their children and their homes are all good opening topics for conversation. Don't talk about yourself, your troubles or your work, unless asked.

Avoid expressing definite opinions on controversial subjects, for they often lead to unpleasant arguments. Ridicule of another person is likewise taboo at all times. If you can't say pleasant things about others, keep quiet. Finally, reserve technical discussions for technically minded listeners.

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ACHIEVEMENT THROUGH ELECTRONICS

HOW RADIO-FREQUENCY AMPLIFIERS WORK

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HOW RADIO-FREQUENCY AMPLIFIERS WORK

B203

STUDY SCHEDULE

☐ **1. Introduction . . . . Pages 1-4**
Here we take a look at a basic rf amplifier.

☐ **2. Practical Facts about Resonant Circuits . . . . Pages 5-15**
In this section you review resonant circuits, and learn why the bandwidth they will pass is important.

☐ **3. Radio-Frequency Voltage Amplifiers . . . . Pages 15-25**
We review the basic arrangement of a superheterodyne receiver, then we take up pentode and triode tube rf amplifiers, transistor rf amplifiers and field-effect transistor rf amplifiers.

☐ **4. I-F Amplifiers . . . . Pages 26-33**
You study tube and transistor i-f amplifiers for both radio and TV receivers.

☐ **5. Radio-Frequency Power Amplifiers . . . . Pages 34-42**
You learn about both vacuum tube and transistor power amplifiers.

☐ **6. Answer Lesson Questions.**

☐ **7. Start Studying the Next Lesson.**

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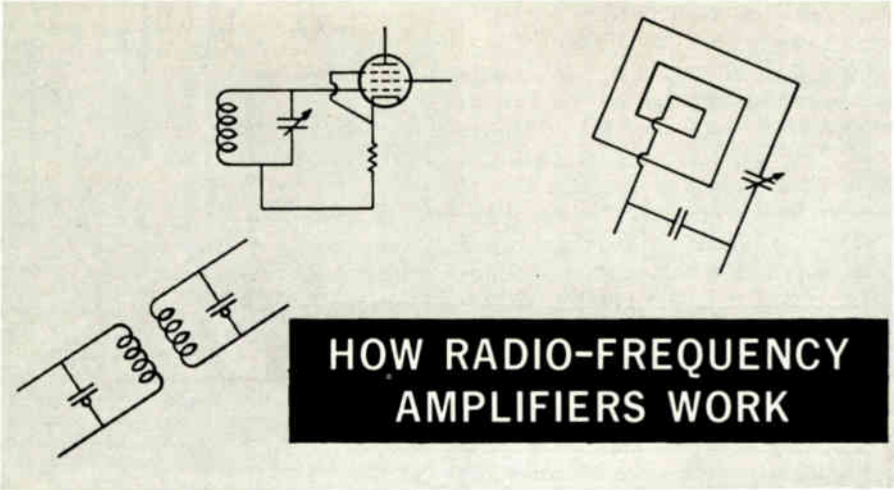


HOW RADIO-FREQUENCY AMPLIFIERS WORK

A radio-frequency amplifier is an amplifier designed to amplify signal frequencies above the sound or audio range. Some radio-frequency amplifiers are designed to operate at frequencies as low as 20 or 30 kilocycles; you will find amplifiers of this type in very low-frequency communications equipment. Other radio-frequency amplifiers are designed to operate at frequencies of several hundred megacycles. The radio-frequency amplifier found in the vhf tuner of a television receiver must be able to operate at frequencies over 200 megacycles in order to amplify signals from TV Channels 11, 12 and 13. As you will see in this lesson, the operation of low-frequency radio-frequency amplifiers is essentially the same as those designed to operate in the very high-frequency regions although some of the problems encountered in amplifiers operating at several hundred megacycles or more are not encountered in amplifiers operated at low frequencies.

Radio-frequency amplifiers are usually referred to as rf amplifiers. RF amplifiers are found in all types of electronic equipment. Modern radio and television receivers all contain rf amplifiers. RF amplifiers are used in all types of communications equipment designed to transmit or receive information by means of radio waves ranging from simple inexpensive portable receivers up to the complex radio systems designed to keep in touch with satellites and relay information about the earth or other planets from the satellite back to earth.

RF amplifiers perform two important functions. They amplify weak radio-frequency signals and they help select the desired signal while rejecting undesired signals.

The signal transmitted by a radio or television station is comparatively weak by the time it reaches the antenna of the radio or television receiver. Before the information contained in that signal can be extracted from it, the strength of the signal must be built up. Radio and television receivers have rf amplifiers in them to build up the weak signal picked up by the receiving antenna.

As you probably already know, in this country there are hundreds of radio stations sending out signals in the standard radio broadcast band; there are several hundred television stations sending out television signals; and in addition there are thousands of stations used for commercial communications. A radio or television receiver must be able to select the one signal you are interested in from all these and reject the others. The various radio broadcast stations in one locality all operate on different frequencies. Your receiver has rf stages in it that can be tuned to respond to one frequency while rejecting signals of other frequencies. Thus, in addition to amplifying the weak signals picked up by your receiving antenna the rf amplifier helps to select the one signal you want and reject the others.

In modern superheterodyne receivers you will remember that the incoming signal is mixed with the signal generated by a local oscillator (in the set) and a new signal frequency is produced. This frequency is called the intermediate (i-f) frequency. This i-f is actually an rf frequency and the amplifiers designed to amplify it are rf amplifiers. However, to distinguish between these amplifiers and the ones that amplify the incoming signal before its frequency is changed, they are usually called i-f amplifiers. Our discussion in this lesson will cover both the rf amplifiers that amplify the signal before the signal frequency is changed and the i-f amplifiers that amplify it after the signal frequency has been changed.

Because rf amplifiers are so widely used in both transmitting and receiving equipment, they are considered a basic circuit and all technicians should be familiar with and understand their operation. You will run into this type of amplifier regardless of what branch of the electronics field you work in. Before we go further into the subject let's see what a basic rf amplifier looks like.

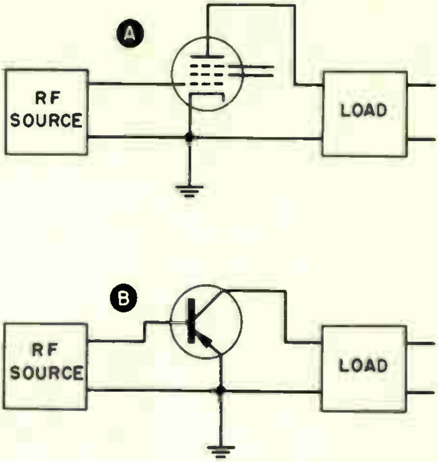


Fig. 1. Two basic rf amplifiers are shown above. Notice that they are similar to the low-frequency amplifiers you have already studied.

A BASIC RF AMPLIFIER

Two basic rf amplifiers are shown in Fig. 1. In Fig. 1A we have shown a circuit using a vacuum tube. We have not shown the screen-grid or suppressor-grid connections to the tube nor have we shown any bias on the tube, because they do not enter into our consideration of the basic rf stage. Notice that the rf source signal is applied between the grid and the cathode of the tube, and that there is a load in the plate circuit of the tube. The amplified rf signal voltage is developed across this load.

In the circuit shown in Fig. 1B we have shown a transistor using a common emitter circuit. Again, the rf signal source is applied between the base and the emitter, and the load is placed in the collector circuit of the transistor. The amplified signal voltage appears across the load.

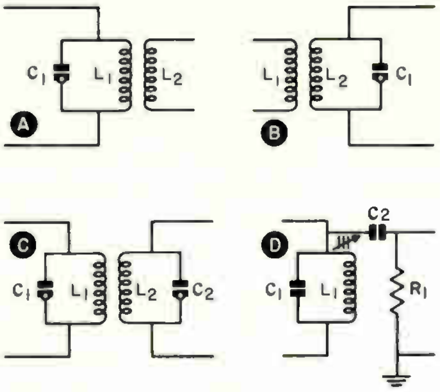


Fig. 2. Four basic loads which might be found in rf amplifiers.

At first glance it may appear that these circuits do not differ appreciably from the low-frequency amplifiers that you have already studied. However, there is a big difference, and that difference is in the load used in the output circuit of the rf amplifier. RF amplifiers almost always use some type of resonant circuit as the load.

Four basic loads which might be found in rf amplifiers are shown in Fig. 2. In the circuit shown in Fig. 2A we have an rf transformer. Coils L_1 and L_2 are inductively coupled together. The primary L_1 is tuned to resonance by the capacitor C_1. The parallel resonant circuit thus formed is connected into the plate circuit of the rf amplifier.

In Fig. 2B we have another type of rf transformer. Here L_1 and L_2 are again inductively coupled together. In this circuit, however, the secondary, L_2, is tuned to resonance by C_1. Thus, instead of having the resonant circuit in the output circuit of the rf amplifier we simply have L_1 in the output circuit, and the resonant circuit is in the input of the following rf stage.

In the circuit shown in Fig. 2C we have another type of rf transformer. Again, L_1 and L_2 are inductively coupled together, but in this circuit both L_1 and L_2 are tuned to resonance. L_1 is tuned to resonance by C_1, and L_2 is tuned to resonance by C_2. This type of rf transformer is found in the i-f amplifiers of most radio receivers and some TV receivers.

Another load that might be found, particularly in TV receivers, is shown in Fig. 2D. In this circuit C_1 is a fixed capacitor and L_1 a variable inductance. The circuit is tuned to resonance by adjusting a slug which moves in and out of L_1 to vary the inductance of the coil. This method of varying the inductance in the circuit rather than the capacity could also be used in circuits like those shown in Figs. 2A, 2B, and 2C. L_1 and C_1 form a parallel resonant circuit. The signal appearing across this parallel resonant circuit is coupled to the following stage through capacitor C_2. In some high-frequency circuits, C_1 in Fig. 2D is omitted. The output capacity of the tube or transistor and the wiring capacity in the circuit take the place of C_1.

This brief look at the basic rf stage and the loads that you are likely to find in the plate circuit of this type of stage should immediately point out to you the importance of resonant circuits in rf amplifiers. The operation of an rf amplifier stage is quite similar in many respects to that of the low-frequency amplifiers that you have already studied. The big difference is in the use of resonant circuits in rf amplifiers. Therefore, before going ahead with our study of the rf amplifier let's learn more about resonant circuits.

For many years we have used the expressions cycles per second, kilocycles per second and megacycles per second to describe the frequency of repetitive waves. For example, a sine wave is a repetitive waveform; it simply repeats itself over and over again. The frequency of the power line voltage, which is a sine wave, is 60 cycles per second.

In place of the expression, cycles per second, a new term, the Hertz, is now being used. Hertz was a physicist who many years ago studied radio wave propagation. No unit in electricity has been named after him and hence the term Hertz was designated as an honor to him and also as a unit of frequency measurement. One Hertz is equal to one cycle per second. 60 Hertz is equal to 60 cycles per second. We usually abbreviate the word Hertz Hz, thus instead of writing the power-line frequency as 60 cps we can write it as 60 Hz.

In addition to the unit Hertz we have the kilohertz and the megahertz. The kilohertz is abbreviated KHz and is equal to 1000 cycles per second or 1 kilocycle per second. The term megahertz is usually abbreviated MHz and is equal to 1,000,000 cycles per second or 1 megacycle per second. Notice that the term Hertz not only identifies the number of cycles, but also the time as one second. Thus to properly describe the power line frequency we can say 60 Hz, but if we use cycles, we must say 60 cycles per second.

You'll find the term cycles per second, kilocycles per second and megacycles per second used in all the older textbooks and magazines. Even some later textbooks still use these units. However, the general trend is toward adopting the new terms Hz, KHz, and MHz. Since you need to be familiar with both sets of units, we will use both in the following lessons. It will be worthwhile to take time now to memorize the equivalents.

1 Hertz (Hz) = 1 cycle per second (1 cps)
1 Kilohertz (KHz) = 1 kilocycle per second (kc ps)
1 Megahertz (MHz) = 1 megacycle per second (1 mc ps)

Practical Facts about Resonant Circuits

In an earlier lesson on resonant circuits you learned that there are two types of resonant circuits, series resonant circuits and parallel resonant circuits. In Fig. 3 we have shown these two resonant circuits. A series resonant circuit is shown in A and a parallel resonant circuit at B.

At this time it might be well to point out again that whether a circuit is a series resonant circuit or a parallel resonant circuit depends not on how the components are connected, but on how the voltage is applied to the circuit. If the voltage is applied in series with the coil and capacitor, as in Fig. 3A, the circuit is a series resonant circuit, but if it is applied across the coil and capacitor in parallel as in Fig. 3B, then the circuit is a parallel resonant circuit. Keep this point in mind; you will run into both series resonant and parallel resonant circuits in all types of communications equipment. It is not always easy to tell whether the circuit is a series resonant or a parallel resonant circuit simply by looking at it, but if you consider how the voltage is applied to the circuit, you can usually tell which type it is without too much difficulty.

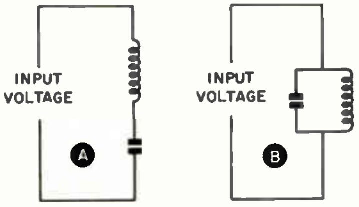


Fig. 3. A series resonant circuit is shown at A; a parallel resonant circuit at B.

Now let us quickly review what we already know about resonant circuits. We know that a circuit will be at resonance when the inductive reactance (X_L) of the coil is exactly cancelled by the capacitive reactance (X_C) of the capacitor. You know that this will occur for any given coil and capacitor at one frequency and only one frequency. The circuit will be resonant at this one frequency. In other words, if we take any coil and connect a capacitor across it, at some frequency that circuit will be resonant because the inductive reactance of the coil will be exactly cancelled out by the capacitive reactance of the capacitor.

The fact that a resonant circuit is resonant at only one frequency does not mean that it will respond only to that exact frequency. In fact, it will respond to a band of frequencies around the resonant frequency. For example, if we apply a voltage to a series resonant circuit and change the frequency of the voltage source, we will find that at resonance we get a maximum current flow through the resonant circuit. If we increase the frequency slightly above the resonant frequency, we will find that the current drops slightly. If we increase the frequency of the voltage source still more, the current will drop a little more. If we increase the frequency still further, the current will drop still further. Similarly, if we reduce the frequency below the resonant frequency, we will find that the current flowing in the circuit is slightly less than the current flowing at resonance. If we reduce the frequency still more, the current will be still less. In other words, at resonance we get a maximum current flow through the resonant circuit and at frequencies either above or below the resonant frequency, the current is somewhat less than it is at the resonant frequency. The further we get away from the resonant frequency, the lower the current will be.

Actually, instead of responding to a single frequency, the resonant circuit will respond to a band of frequencies around the resonant frequency. How wide a band of frequencies it will respond to depends upon the Q of the circuit. If the Q of the resonant circuit is high, any appreciable deviation from the resonant frequency will cause an appreciable change in output. However, if the Q of the resonant circuit is low, there must be a substantial deviation from the resonant frequency before the output of the resonant circuit changes appreciably.

You might at first think that the fact that a resonant circuit will respond to a band of frequencies rather than a single frequency is a disadvantage. However, this is not the case. In fact, if a resonant circuit would pass only a single frequency or a very narrow band of frequencies, then the radio and TV systems that we have today would not be practical. To see why this is so and to help us get a better understanding of what a resonant circuit in an rf amplifier must do, let's once again consider the type of signal that is actually transmitted by a radio or television broadcast station.

SIDEBAND FREQUENCIES

In a radio or television broadcast station, one section of the transmitter generates a radio-frequency signal which is known as the carrier or carrier wave. This is the radio-frequency signal that travels through space and carries either the sound or picture signals being transmitted by the broadcast station. However, a radio-frequency carrier itself is of no value unless we add intelligence to it. The earliest method of using this carrier signal was by interrupting it in a series of dots and dashes to send messages by code. However, even though this is useful in communications work, it is of no value in transmitting radio and television programs for entertainment purposes.

In order to transmit a radio program, the sound or audio signal must be superimposed on the radio frequency carrier. We call this process of superimposing the sound signal on the carrier, modulation.

In the modulation process certain additional frequencies other than the original carrier frequency are produced. For example, let us consider a radio station broadcasting on a carrier frequency of 1000 KHz. If we modulate this signal with a 1000-cycle (1 KHz) signal, we will produce two new frequencies in the modulation process. The 1 KHz audio signal when it is used to modulate the 1000 KHz carrier will produce two new signals, one equal to the sum of the carrier frequency and the audio frequency, and a second signal equal to the difference between the carrier frequency and the audio frequency. In other words, we will produce a signal of 1001 KHz and a signal of 999 KHz. The 1001 KHz signal and the 999 KHz signal are called the sideband signals. The higher of the two sidebands is called the upper sideband and the lower of the two is called the lower sideband.

Now, if we wish to be able to receive this modulated signal on a radio receiver, we must be able to receive not only the original 1000 KHz carrier, but also the two sideband frequencies. The sideband frequencies are the frequencies that actually carry the 1000-cycle audio signal superimposed on the carrier. Therefore, if we had a resonant circuit in our receiver that would respond only to a frequency of 1000 KHz and no other signal frequencies, we would not be able to pick up the 999 KHz and the 1001 KHz signal along with the 1000 KHz signal, and hence we would not be able to receive the modulation on the 1000 KHz carrier.

Fortunately resonant circuits have what is called a bandwidth. This simply means that the resonant circuit will respond to a band of frequencies around the resonant frequency and hence we would have no difficulty designing a resonant circuit that would respond not only to the 1000 KHz carrier signal, but also to the 999 KHz and the 1001 KHz sideband frequencies.

As you will see later, the resonant circuits in radio and television receivers must be able to respond to frequencies substantially above or below the resonant frequency. We will go into this shortly, but first let's look into what we mean by the bandwidth of a resonant circuit and some of the factors that affect the bandwidth.

BANDWIDTH

As we pointed out in the preceding section, a resonant circuit will pass a band of frequencies rather than a single frequency. However, if we move away from the resonant frequency the output that will be obtained from the resonant circuit decreases. In other words, if we are 50 KHz away from the resonant frequency you will not obtain as high an output from the resonant circuit as we would at the resonant frequency.

In Fig. 4 we have shown a voltage response curve of a typical resonant circuit that is resonant at a frequency of 1000 KHz. A response curve is simply a curve that shows how the circuit responds to signals at or near the resonant frequency. Notice that at the resonant frequency of 1000 KHz, the circuit peaks; in other words, the output voltage from the circuit is at its maximum value at a frequency of 1000 KHz. As the frequency is increased or decreased from the resonant frequency, the voltage produced across the circuit begins to go down. Notice, however, that although the circuit is resonant and the voltage is highest at a frequency of 1000 KHz, there is some voltage developed across it when the frequency is as low as 900 KHz and also when it is as high as 1100 KHz. This means that this circuit tuned to 1000 KHz when used in a receiver, will pass, to some extent, frequencies as low as 900 KHz and as high as 1100 KHz. However, the output at these frequencies is substantially below what it is at 1000 KHz.

Engineers have arbitrarily set a standard by which they measure the bandwidth of a resonant circuit. To

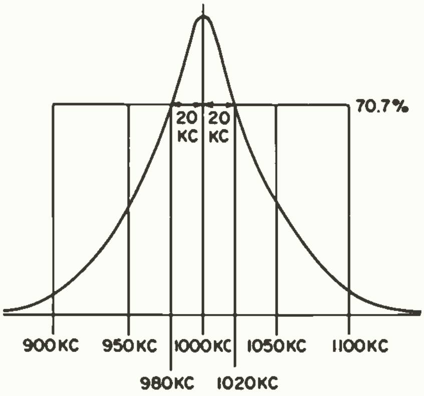


Fig. 4. A response curve showing the two 70.7% points. The bandwidth extends 20 kc on each side of this resonant frequency.

determine the bandwidth of a circuit you find the points at which the output voltage falls to 70.7% of what it is at the resonant frequency. As shown in Fig. 4 these points are at 980 KHz and 1020 KHz. The difference in frequency between these two frequencies is called the bandwidth of the amplifier. In other words, the bandwidth of this amplifier is 40 KHz. It will pass frequencies up to 20 KHz above and down to 20 KHz below the resonant frequency, with at least 70.7% of the output that will be obtained at the resonant frequency.

As in low-frequency amplifiers, the points at which the voltage falls to 70.7% are called the half-power points.

Now the question might come up, do all resonant circuits have the same bandwidth? The answer is no; the bandwidth depends upon the L-C ratio of the resonant circuit and on the Q of the resonant circuit. You will remember that there are many different combinations of L and C that will resonate at a given frequency. Different combinations will have different bandwidths. Furthermore, the Q of the resonant circuit, which is determined chiefly by the inductive reactance of the coil and the resistance in the resonant circuit, will have an effect on the bandwidth of the circuit.

In actual practice the bandwidth of the circuit is sometimes altered by loading the circuit with resistance. In Fig. 5A we have shown a typical parallel resonant circuit. In Fig. 5B we have shown the circuit loaded with a resistor. In Fig. 5C curve 1 shows the bandwidth of the resonant circuit alone and curve 2 shows how the bandwidth is altered by connecting the resistance in parallel with the coil and the capacitor. Notice that curve 2 does not come to as high a peak at the resonant frequency. This indicates that the output from the resonant circuit has been reduced by loading the circuit. However, the bandwidth of the circuit has been increased. Often, it is desirable to sacrifice output in order to obtain a wide bandwidth; this is frequently accomplished by loading the circuit with a resistance. The lower the value of resistance, the lower the output and the wider the bandwidth of the resonant circuit.

Loading resonant circuits by connecting resistors across them reduces the Q of the circuit. It is seldom necessary to do this in radio receivers because the required bandwidth can be obtained by the correct design of the tuned circuit. In fact you do not want too wide a bandwidth because you must have sufficient selectivity to be able to select the one signal you want from among many signals picked up by the receiver. The ideal arrangement is a circuit with a wide enough bandwidth to pass all the sidebands being transmitted by the station and enough selectivity to reject all signals beyond the sideband frequencies. However, you will find that in TV receivers the resonant circuits are frequently loaded by connecting resistors across them in order to get the wide bandwidth needed to pass all the sidebands that carry the picture and color detail.

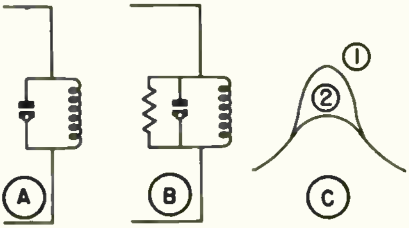


Fig. 5. The response curves at C show the effect of loading a parallel resonant circuit as at B.

COUPLING RESONANT CIRCUITS

RF stages are frequently coupled together by means of rf transformers. A typical example of this type of transformer is an i-f transformer. An i-f transformer consists of two resonant circuits as shown in Fig. 6A. One resonant circuit is used as the load in the output circuit of one stage and the other resonant circuit is used as the input in the following stage. This double resonant circuit helps to improve the selectivity of the receiver. Selectivity is the ability of the receiver to receive the desired signal and reject undesired signals. As we pointed out, the receiver must have enough selectivity to reject undesired signals from stations operating near the frequency of the desired signal.

A photograph showing construction of an i-f transformer is shown in Fig. 6B. Notice that the two coils are wound on a round cardboard form. The coils are not wound on top of each other nor are they placed exactly side by side; you can see that there is some spacing between the two coils. However, in spite of this spacing, the coils are close enough so that they are inductively coupled together.

The exact spacing between the two coils affects the degree of coupling between the two coils. In other words, if the spacing is great, not all the lines of force produced by the primary will cut through the secondary. There is some maximum spacing beyond which some of the lines of force produced by the primary will be lost and will not cut the secondary.

An example of the effect of varying the spacing between the two coils is shown in Fig. 7. If we apply a signal from a variable frequency generator to the primary and measure the output voltage across the secondary as the frequency is varied, we would obtain data from which we could plot curves like those shown. Curve 1 shown in Fig. 7A represents a certain spacing between the two coils, where the coils are pushed quite far apart. As the coils are pushed closer together the output across the secondary will increase until eventually a point is reached where maximum output is obtained as shown in curve 2 at B. If the coils are pushed still closer together we find that the output at the resonant frequency drops somewhat, as shown in curve 3 in Fig. 7C, but rises slightly above and slightly below the resonant frequency, producing two humps in the response curve with a valley in between them. This is often called a double-hump curve. If we push the coils still closer together, the response curve will be still broader. The two peaks have a tendency to move somewhat farther apart and drop in height, and the valley in the center becomes more pronounced.

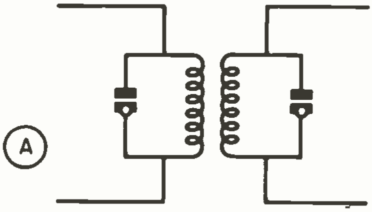


Fig. 6. A schematic diagram of an i-f transformer is shown at A; a photo at B.

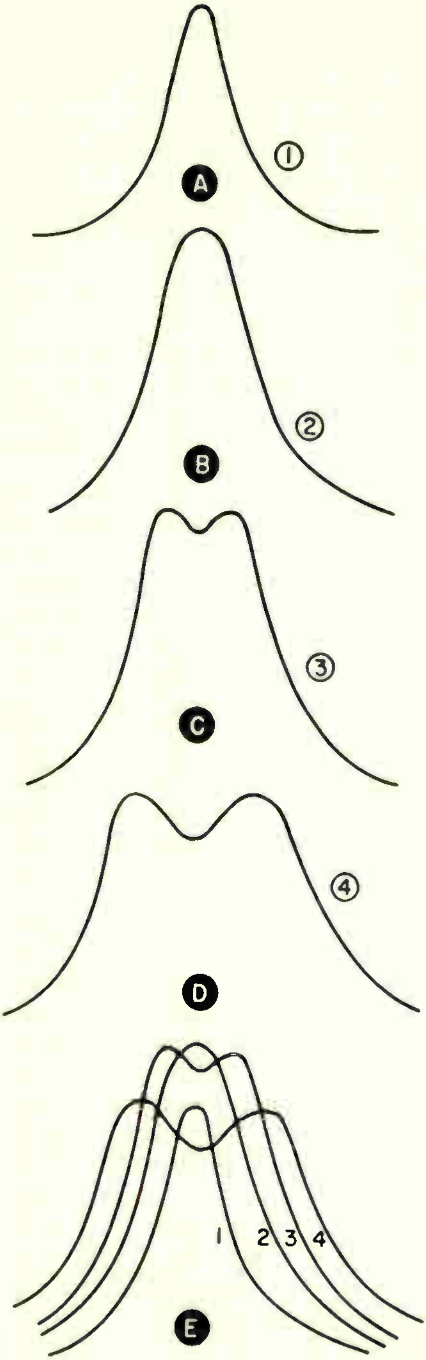


Fig. 7. Response curves showing how coupling affects bandwidth and response.

The four curves shown in A, B, C, and D have been superimposed on a single drawing at E so you can see the effect of changing the spacing between the coils.

As the coils are pushed closer together some point is reached where the output from the secondary is at a maximum value. Reducing the spacing beyond this point results in the two humps in the curve appearing. At the point where the output is maximum and just before the humps in the curve begin to appear, we have what is called critical coupling. If the coils are spaced farther apart than this particular spacing we say that they are under-coupled, in other words the coupling is less than critical coupling. If the coils are pushed closer together than this spacing, we say that the circuits are over-coupled, in other words the coupling is tighter or closer than critical coupling.

As a technician you will not have to adjust the spacing between the primary and secondary coils on an i-f transformer. They will already be adjusted for you by the manufacturer. The i-f transformers in a broadcast-band radio receiver are usually adjusted at, or slightly beyond, the critical coupling point. The i-f transformers in a communications receiver are usually adjusted below the critical coupling point. The i-f transformers in an FM receiver or in the FM sound section of a television receiver are adjusted somewhat beyond the critical coupling point.

In the early days of television, double-tuned i-f transformers were used in the video (picture) i-f amplifier stages. These transformers were very heavily overcoupled, and in addition, they were usually loaded by resistors in order to reduce the Q of the primary and secondary circuits and obtain a very wide bandwidth.

However, modern TV receivers usually employ what is called bifilar wound transformers. A transformer of this type is shown in Fig. 8A. Notice that the secondary winding is wound directly over top of the primary winding in order to obtain as tight coupling as possible between the two windings. Bifilar windings are usually represented schematically by the symbol shown in Fig. 8B. The fact that the coils are interwound so that the primary turns are mixed directly with the secondary turns is schematically represented. The advantage of the bifilar wound transformer is that the coupling between the two coils is very tight. A single slug is used to adjust the resonant frequency of the circuit. The two coils are so tightly coupled that they act like one coil. The output capacity of the stage driving the primary circuit is in effect directly in parallel with the input of the second stage. The net result is that the single slug can be used to adjust the two circuits to resonance at the same frequency. Bifilar wound coils are excellent where a wide frequency band is needed. This situation is encountered in the video i-f amplifier of a television receiver as you will see later.

There are reasons for using the various types of coupling in each of the particular applications mentioned. In a radio receiver designed to receive radio signals on the standard broadcast band the receiver must be able to pass the carrier wave of the broadcast station plus its sidebands. In the standard broadcast band the sidebands do not extend too far above and below the carrier frequency and therefore an extremely wide bandpass is not required.

In communications receivers the primary purpose of the receiver is to be able to receive information. Often the station that you are listening to may be operating very close to other more powerful stations. Here you want as much selectivity as you can get. Therefore the i-f coils are set either at or below critical coupling in order to get as much selectivity as possible from the transformer. If some of the sidebands of the signal are missing this will not be too important. In communications circuits where communications receivers are used, you are usually interested in receiving voice transmission, and the frequency range of the human voice is comparatively limited.

A much wider bandwidth is used in FM transmitters than in AM transmitters. In FM transmissions, the amplitude of the signal transmitted by the FM station does not vary. Instead, the frequency of the signal is varied. It can be varied in the standard FM broadcast station as much as 75 kilohertz above or 75

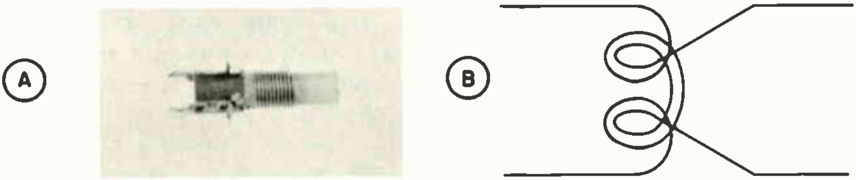


Fig. 8. Bifilar wound transformers are used in modern T.V. A is a photo; B is the schematic symbol.

kilohertz below the center frequency or resting frequency as the carrier frequency of the FM station is called. The rate at which the signal varies above and below the resting frequency is determined by the frequency of the audio signal being transmitted. How far above and below the resting frequency the signal varies is determined by the amplitude of the audio signal. A loud signal can produce sidebands two hundred KHz wide. Therefore the FM broadcast receiver must be capable of passing all these sideband frequencies, particularly if the FM station is a high-fidelity station.

The FM sound system in a television receiver is called narrow band FM. Here the maximum deviation above and below the sound carrier frequency is limited to 25 kilohertz. The rate at which the carrier resting signal is varied above and below the carrier frequency is again determined by the frequency of the signal being transmitted and the amount varied with the amplitude. Even with the deviation limited to 25 KHz, sideband frequencies considerably in excess of 25 KHz are easily produced. The sound i-f transformer must pass this band of frequencies in a TV receiver or the sound signals will be distorted.

In a TV receiver the picture signal consists of a carrier plus the modulation information on it. The modulation signal may produce sidebands up to 4 megahertz wide. Therefore in order to reproduce the sidebands the i-f bandwidth on the TV receiver must be comparatively wide. In color TV, a subcarrier having a frequency of about 3.5 MHz is used. This produces a video i-f signal that is 3.58 megahertz lower in frequency than the video i-f carrier. If the i-f bandwidth of the receiver is not wide enough to pass the video carrier signal, sidebands and the color subcarrier, then the set could not reproduce a color picture. Later in your course when you study television in detail you will understand why it is important that the video i-f amplifier of a television receiver have such a wide bandwidth.

SERVICING NOTES

We have already pointed out that a high Q resonant circuit not only has better selectivity than a low Q circuit, but also for a given input has a higher output. Thus if a piece of electronic equipment is designed with high Q resonant circuits, anything that lowers the Q of the circuits will reduce the gain and the selectivity of the equipment. The chances are that you may not notice a change in selectivity, but it is quite likely that you will notice that the gain of the equipment has fallen off appreciably.

There are several things that might reduce the Q of a resonant circuit. Coils can absorb moisture. Often in damp weather dust or other particles will settle on the coil and adhere to it. Both of these effects will introduce resistance in the circuit, lowering the Q of the circuit and changing both the output and the selectivity.

Sometimes the low Q is due to a poorly soldered connection in a resonant circuit. If the connection is not properly soldered, it may work well for a while and then develop trouble. Poor connections of this type often get through the factory inspection. Holding a hot soldering iron on suspected connections until the solder flows freely over the leads will usually clear up this type of trouble.

You will frequently find in servicing radio receivers that have been in use for many years, that even though you replace defective tubes so that you have all good tubes in the set and all operating voltages throughout the set are normal, the gain of the receiver is not all it should be. When realigning the set does not clear up the trouble, the difficulty is often due to the fact that the Q of one or more of the resonant circuits has fallen off because of moisture or dirt absorption. In a situation like this you must find the resonant circuit causing the trouble and replace it to restore the equipment to its original gain and selectivity.

Trouble of this type is not often found in transistor radios or in TV receivers. As we pointed out, this is something that occurs after a receiver has been used for many years. Most transistor radios are too new to have developed this kind of trouble. The trouble is not found in TV receivers, because usually the resonant circuits in the television receiver are very heavily loaded in order to give the wide bandwidth needed to pass the picture signal.

Resonant circuits are tuned to resonance by adjusting the capacity or the inductance in the circuit so that the inductive reactance of the coil is exactly equal to and cancels out the capacitive reactance of the capacitor at the resonant frequency. Any further change of either the inductance or the capacitance in the circuit will shift the resonant frequency of the circuit.

Both tubes and transistors have a certain amount of internal capacitance. For example, in an i-f tube there is capacity between the grid and the cathode and between the grid and the screen. The screen is grounded insofar as rf is concerned so that the grid-to-screen capacity is effectively placed between the grid and ground. The cathode of the tube is usually operated at rf ground potential so that the grid-to-cathode capacity is placed directly between grid and ground. Thus if the input of the tube is connected across a resonant circuit, the tube capacities affect the resonant circuit. If an i-f amplifier is aligned with one tube in a circuit and then a different tube is installed, it is likely that the new tube will not have exactly the same input capacity as the old one. As a result, installing the new tube in the circuit will slightly detune the resonant circuit. Radio receivers designed for broadcast band reception are usually fairly broad, so the change in capacity will not be enough to cause trouble. However, if you change two or three tubes in an i-f amplifier of a TV receiver the resonant frequency of the various circuits in the i-f amplifier may be altered enough to appreciably alter the bandwidth of the i-f amplifier so that it can no longer pass all the sideband frequencies and there will be some loss in picture detail. In transistor equipment you have capacity between the emitter and the base and between the base and collector which can have the same effect on resonant circuits.

In communications receivers designed to provide good selectivity in order to separate stations operating very close together, changing one or more tubes or transistors in one of the tuned circuits such as the rf amplifier, mixer, or i-f stages will usually alter the resonant frequency of the particular circuit involved to such an extent that the selectivity of the receiver will suffer. This is particularly true of stages designed to operate at high frequencies.

Disturbing the wiring in a resonant circuit designed for operation at a high frequency may change both the inductance and capacity in the circuit. Even a straight short piece of wire has a certain amount of inductance. At the comparatively low frequencies used for standard radio broadcasting a straight short piece of wire has so little inductance that it can be ignored. However when you get up into the higher frequencies such as those used for TV and FM broadcasting, even the smallest inductance becomes important. Changing the length of a wire in a critical circuit may have some effect on the resonant frequency because the inductance in the circuit is changed. Also moving the position of a wire in a resonant circuit operating at a high frequency and pushing it closer to a metal chassis or moving it further away from the metal chassis may change the capacity of the circuit. There is always capacity between the wires in a resonant circuit and the chassis or ground. Moving the wires around in a broadcast-band receiver is not likely to cause any trouble, but changing the position of a wire in a high-frequency circuit will frequently have an appreciable effect on the circuit.

These points are very important and are worth remembering when working on resonant circuits found in TV receivers or any other equipment designed for high-frequency operation. When it is necessary to make repairs on components in or near resonant circuits, it is a good idea to avoid disturbing the parts and leads as much as possible. If you have to move a lead to get at another part in order to replace it, try to put the lead back in as close as possible to the original position. Often this is an unnecessary precaution, but it is a precaution that can keep you out of difficulty in some critical circuits.

Much of the material covered in this section has been a review for you, but now that you have the important points about resonant circuits fresh in your mind you are ready to go ahead with your study of rf amplifiers.

SELF TEST QUESTIONS

(a) What is the basic difference between the circuit used in an rf amplifier and the circuit used in an audio amplifier?

(b) What is the basic difference between a series-resonant and a parallel-resonant circuit?

(c) What are sideband frequencies?

(d) What do we mean by the bandwidth of a resonant circuit?

(e) On what factors does the bandwidth of a resonant circuit depend?

(f) How can the bandwidth of a given parallel-resonant circuit be increased?

(g) What do we mean by critical coupling between two coils?

(h) What do we mean by overcoupling?

(i) What happens to a resonant circuit that absorbs moisture, and dust and particles settle on the coil and adhere to it?

(j) Why should you avoid moving any of the wires in the rf section of a TV receiver?

Resonant circuits are extremely important in rf amplifiers. If you think you may have forgotten some of the details you learned about resonant circuits it would be a good idea to spend some time reviewing to be sure you understand and remember the important characteristics of both series and parallel-resonant circuits. This will help you in these sections of the lesson to follow where we'll go into detail about both vacuum tube and transistor radio-frequency amplifiers.

Radio-Frequency Voltage Amplifiers

A block diagram of a superheterodyne receiver is shown in Fig. 9. You have seen this block diagram before. The rf amplifier is the stage connected to the antenna. The weak signal from the antenna is fed to the rf stage where it is amplified and then fed to the mixer. The rf stage also has tuned circuits so that it provides a certain amount of selectivity. In other words, it helps select the desired signal and reject undesired signals.

The signal from the rf amplifier is fed to a mixer-oscillator stage. In this stage the incoming signal is mixed with a locally generated signal and a new signal is produced. This signal that we are interested in is called the intermediate-frequency signal. It is equal in frequency to the difference between the incoming signal and the oscillator signal. This intermediate-frequency signal, or i-f signal as it is called, is fed to an i-f amplifier where it receives further amplification. The signal is still a radio-frequency signal so strictly speaking the i-f amplifier is a radio-frequency amplifier. However, it operates at much lower frequencies than the rf amplifier that precedes the mixer. From the i-f amplifier the signal is then fed to a second detector where the intelligence on the carrier wave is removed and then it is fed to a low-frequency amplifier. In the case of a radio receiver the signal is then fed to a speaker; in the case of a television receiver the sound signal is fed to a speaker and the picture signal is fed to the picture tube and to various other circuits you will study later.

The circuit we are going to be concerned about in this part of this lesson is the rf amplifier used between the antenna and the mixer. This stage is omitted in some of the small low-cost radio receivers, but it is invariably found in the better receivers and television receivers.

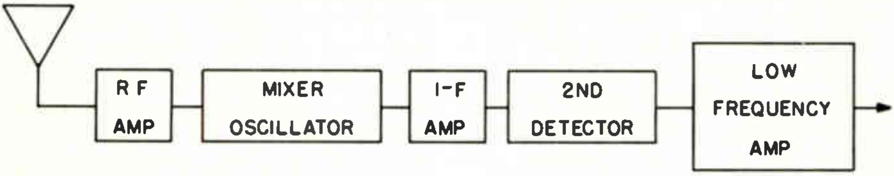


Fig. 9. A block diagram of a typical superheterodyne receiver.

The stage is a voltage-amplifier stage. In later sections of the lesson you will study i-f amplifiers and in another section rf power-amplifier stages.

The rf voltage amplifiers used in radio and television receivers are all Class A amplifiers. Some use pentode tubes, some use triode tubes, and some use transistors. You will study all three types in this section of the lesson.

PENTODE RF AMPLIFIERS

A typical rf amplifier using a pentode tube is shown in Fig. 10. This is the type of amplifier that is used between the antenna and the mixer in a communications-type superheterodyne receiver, in a few of the better broadcast-band receivers, and in many FM receivers.

In the circuit shown in Fig. 10, the signal picked up by the antenna causes a current to flow through L_1 which is the primary of the antenna transformer T_1. L_1 and L_2 are wound on the same form and are inductively coupled together. Thus the magnetic field produced by the current flowing through L_1 cuts the turns of L_2 and induces a voltage in series with it. L_2 is tuned to resonance by the capacitor C_1. Since the voltage induced in L_2 is induced in series with it, the combination of L_2 and C_1 forms a series-resonant circuit. The frequency to which this circuit is tuned can be altered by changing the capacity of C_1. This is done by rotating the dial on the receiver, which causes the rotor or moving plates of the tuning capacitor to move in and out between the stator (stationary) plates of the capacitor.

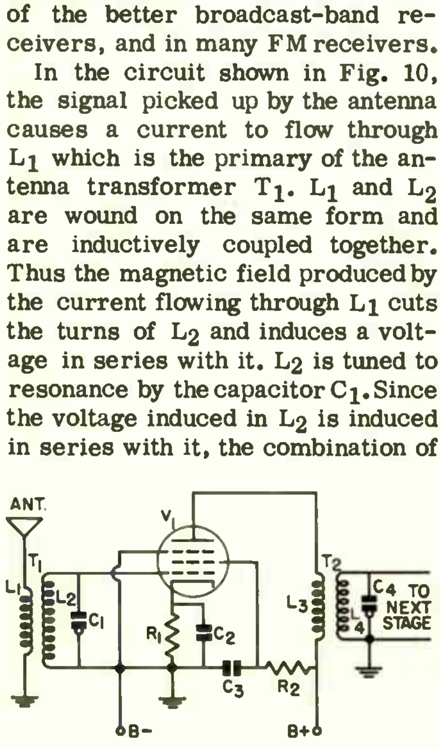


Fig. 10. A typical rf amplifier using a pentode tube.

In some receivers instead of using a variable capacitor such as shown in Fig. 10, a trimmer capacitor is used and a powdered iron slug is used that can be moved in and out of L_2. A trimmer capacitor is a capacitor that is adjusted by means of a screwdriver to adjust the stage at the high-frequency end of the band to be covered. The actual change in the resonant frequency of the tuned circuit required to tune the receiver across the band is then accomplished by moving the slug in and out of the coil L_2. This type of tuning, which is often called permeability tuning, is found more frequently in FM receivers than in broadcast and communications-type receivers.

It makes comparatively little difference whether the frequency of the tuned circuit is varied by varying the inductance of the coil or capacity of the capacitor. Either will change the resonant frequency so that the rf stage can be tuned to the frequency of the signal to be amplified.

We mentioned that L_2 and C_1 form a series-resonant circuit. We have mentioned before that when the voltage is induced in the secondary winding of a transformer, in a circuit of this type, that the circuit is a series-resonant circuit. Fig. 11 is an example of what happens. A small voltage is induced in each turn of the coil. These voltages add up to give you the total voltage induced in L_2. It is more or less like a series of

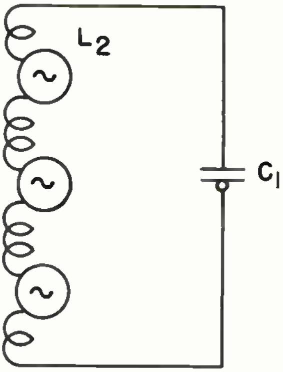


Fig. 11. Voltage induced in L_2 is induced in series with the turns of L_2.

small generators placed in the coil in series with the various turns as shown in Fig. 11. It is important to realize that this type of circuit is always a series-resonant circuit and never a parallel-resonant circuit; it will help you understand better what is happening in the circuit.

You will remember that one of the characteristics of a series-resonant circuit is that there is a high circulating current in the circuit and that there will be a resonant voltage step-up across the coil and across the capacitor. Thus we have the weak signal voltage picked up by the antenna being stepped-up by the resonant circuit. The voltage across the coil and across the capacitor in the resonant circuit is then applied between the grid and cathode of V_1. It is applied directly to the grid of the tube and to the cathode through the cathode-bypass capacitor C_2.

The radio-frequency signal applied between the grid and cathode of V_1 will cause the plate current flowing through V_1 to vary at the same rate as the incoming signal. Remember that L_2 and C_1 will resonate at only one frequency and signals at this particular frequency will normally be stepped up and be much stronger than any other signal.

The varying current flowing through the tube will flow through L_3, which is the primary winding of T_2. L_3 is inductively coupled to L_4 and hence a voltage will be induced in L_4. Again L_4 and C_4 make up a series-resonant circuit. The combination of L_4 and C_4 will be tuned to the same frequency as L_2 and C_1 and hence this resonant circuit will give the signal a still further build up, and at the same time help to reject any signals of a frequency other than the resonant frequency that happened to get by L_2 and C_1 to the grid of V_1.

Thus we have three things increasing the signal voltage. We have the resonant voltage step-up in the L_2 C_1 series-resonant combination, we have the voltage gain that can be obtained from the tube V_1 and a still further voltage step-up in the resonant circuit consisting of L_4 and C_4.

Notice that screen grid of the pentode tube is connected to ground through the capacitor C_3. C_3 is chosen so that at radio frequencies it has a very low reactance, or in other words it acts like a short circuit insofar as radio frequencies are concerned. Thus the screen is said to be at rf ground potential. This simply means that as far as the rf signal is concerned, the screen grid might just as well be connected directly to ground.

The screen grid shields the grid of the tube from the plate so that little or no energy can be fed from the plate of the tube back to the grid of the tube. It is important that we avoid feeding any energy from the plate of the tube back to the grid, otherwise we may have trouble with the stage going into oscillation.

We mentioned that this type of rf amplifier may be found in broadcast band receivers, communication receivers and FM receivers. The main difference between the rf amplifiers found in these different pieces of equipment will be in the number of turns on the coils. In an FM receiver that operates in the vicinity of 100 MHz, the coils L_1, L_2, L_3 and L_4 will usually consist of only one or two turns of a rather large diameter wire. In the broadcast band, the coils will consist of 100 or more turns of a comparatively fine wire. In communications receivers you will find coils all the way between the coils with 100 or more turns used in broadcast receivers to the coils with even fewer turns than those found in FM receivers. The exact number of turns on the coil will depend upon the frequency band the receiver is to cover.

Another pentode rf amplifier is shown in Fig. 12. This is identical to the amplifier shown in Fig. 10 except the capacitor C_5 and resistor R_3 have been added. C_5 is a comparatively large capacitor so that at the signal frequency its reactance is almost zero. Therefore as far as L_2 is concerned it is connected directly to B- and to the rotor of C_1. The signal sees no opposition because the reactance of C_5 is so low. R_3 is a comparatively large resistor so there is no signal fed from R_3 into the circuit we have marked avc.

The purpose of this circuit is to enable us to apply a variable negative voltage to the grid of V_1. The negative voltage applied to the grid of V_1 will control the gain of the tube. The higher the negative voltage, the lower the gain of the tube. The voltage is usually obtained from the detector circuit and the strength of this voltage will depend upon the strength of the signal. This voltage is referred to as the automatic volume control voltage and is used to vary the gain of the stage. If the input signal is very strong, the avc voltage developed will be high and will tend to reduce the gain of the stage. On the other hand, if the signal received is weak, very little avc voltage will be developed and the stage will operate at close to its maximum gain. You will see in a later lesson how this avc or automatic volume control voltage is developed.

As a point of interest, avc is the term used in radio receivers. Actu-

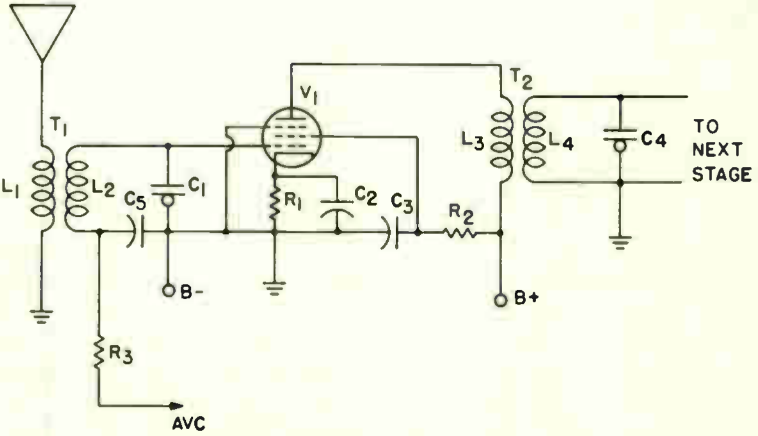


Fig. 12. A pentode rf amplifier modified for automatic gain control.

ally, this is not an automatic volume control, but rather it is an automatic gain control. In television, we use the term automatic gain control, abbreviated agc rather than avc. In television agc is much more suitable because varying the gain of the rf amplifier affects both the picture and sound signals.

TRIODE RF AMPLIFIERS

One of the disadvantages of pentode rf amplifiers is that they generate considerable noise within the tube itself. Part of this noise is often caused by changes in the division of the cathode current between the plate and screen of the tube. Small changes occur at random. These changes are too small to be detected in most cases, but they result in noise being generated within the tube. In the case of radio stations operating in the broadcast band and FM stations, usually the signals are so strong that they simply override this noise and it does not cause any trouble. However, in TV receivers the noise may become objectionable and may appear in the picture, particularly on weak signals. This problem can be overcome by using a triode rf amplifier.

Triode tubes have been especially designed for use as rf amplifiers in vhf tuners of television receivers. The vhf tuner in a television receiver covers channels 2 to 13. A typical triode rf amplifier such as might be found in a television receiver is shown in Fig. 13.

In TV receivers the lead-in or wire used to connect the antenna to the receiver is usually what is called a balanced wire or cable. This cable has two conductors and neither is at ground potential. Each is operated above ground. The resistance or impedance from either wire to ground is the same. We call this type of line a balanced transmission line.

The balanced transmission line is connected to the antenna terminals of the receiver. In the circuit shown in Fig. 13 it is fed to T_1. T_1 is what is called a balun. The purpose of the balun is to match the balanced transmission line to the unbalanced input circuit. An unbalanced input circuit is a circuit in which one side of the circuit is grounded. T_1 serves the

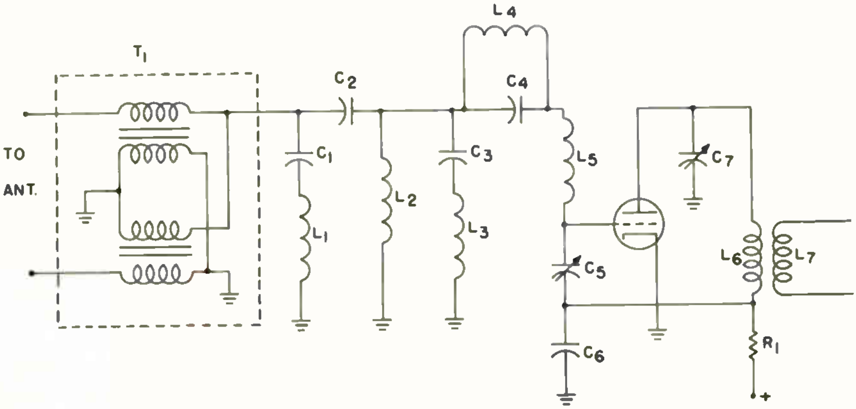


Fig. 13. A triode rf amplifier.

purpose of matching the balanced line to the unbalanced input of the receiver.

The capacitors C_1, C_2 and C_3 along with coils L_1, L_2 and L_3 form what is called a high-pass filter. A high-pass filter is a filter that passes signals above a certain frequency and rejects signals below this frequency. The lowest vhf TV channel is channel 2. The frequency of this TV channel is 54 to 60 megahertz. The high-pass filter is designed to cut out all signals below 54 megahertz and pass signals above 54 megahertz. Thus strong signals from nearby broadcast stations operating the standard broadcast band are prevented from reaching the rf amplifier and causing interference.

The combination of L_4 and C_4 form a parallel-resonant circuit. This circuit is usually a uhf trap and is designed to prevent interference from uhf television signals from reaching the grid of the rf circuit.

L_5 and C_5 form a series-resonant circuit that is resonant to the frequency of the channel received. C_6 is a very large capacitor and insofar as the resonant circuit is concerned has no effect on the circuit.

The signal applied to the grid of the tube is amplified and fed to L_6. The combination of L_6 and C_7 forms a parallel-resonant circuit which is resonant to the frequency of the TV channel.

B+ is applied to the plate of the tube through R_1. The lower end of L_6 is not at ground potential. It is bypassed through C_6. However, C_6 does not bypass all of the signal, but part of it is fed back through C_5 to the grid of the tube. The purpose of feeding this signal back to the grid of the tube is to make up for any signal fed from the plate of the tube back to the grid of the tube through the tube itself. The signal fed from the plate of the tube back to the grid through the tube could cause the stage to go into oscillation. The signal fed from the lower end of L_6 through C_5 to the grid of the tube is 180° out-of-phase with the signal fed through the tube and cancels this signal thereby preventing oscillation. You will remember that when you studied triode tubes before, we pointed out that they would oscillate in rf circuits unless they were neutralized. This is a neutralizing circuit.

In the early days of radio, triode amplifiers were used in broadcast-band receivers, but since the pentode tube was invented, triode tubes have not been used for this purpose. However, you will find triodes in the rf amplifier of TV receivers where the low-noise characteristic of the triode is an advantage over a pentode. The circuit in Fig. 13 is typical. You do not have to memorize this circuit. We will go into it in more detail later when you study TV, but at least you should have an idea of the general circuit configuration and notice that except for the balun and trap in the input circuit, the circuit is not too different from the pentode rf amplifier circuit. Of course, as far as the triode amplifier itself is concerned, the balun, the high-pass filter and the uhf trap could be eliminated and a signal fed directly to the resonant circuit and to the grid of the tube. These other components are needed because of the circumstances under which the amplifier is used.

TRANSISTOR RF AMPLIFIERS

A typical transistor rf amplifier such as might be found in a radio receiver is shown in Fig. 14. The circuits use an NPN transistor in a common-emitter circuit.

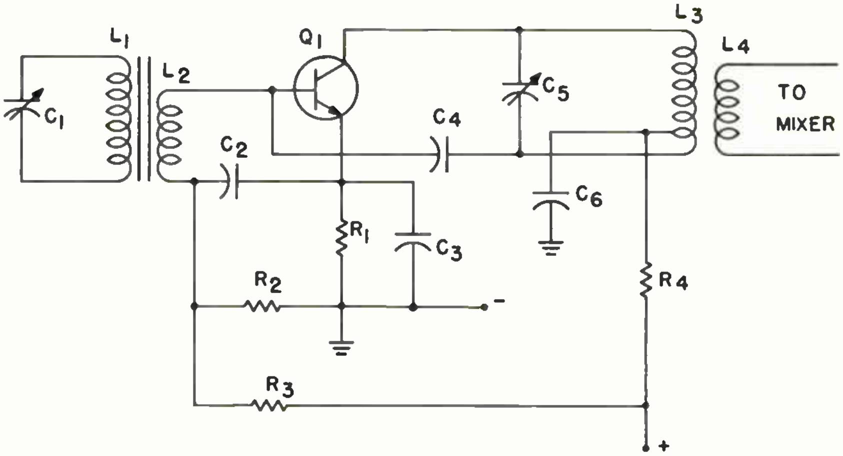


Fig. 14. A transistor rf amplifier.

L_1 is a coil wound on a ferrite rod. A ferrite rod is a rod made of a powdered iron-type material held together by a suitable binder. The coil is wound on this rod to get a very high Q. It is tuned to resonance by C_1 so that the combination of L_1 and C_1 form a series-resonant circuit. The circuit can be tuned to the frequency of the desired station. L_2 is inductively coupled to L_1. Since L_2 has fewer turns than L_1, there will be a current step-up, in other words the current flowing in L_2 will be higher than the current flowing in L_1. This serves two useful purposes; it provides a higher current for the emitter-base circuit of the transistor Q_1, and prevents the transistor from loading the resonant circuit. If it did load the resonant circuit excessively it would lower the Q of the coil and in so doing reduce the selectivity of the circuit.

The signal induced in L_2 is applied to the base of the transistor and to the emitter through C_2. C_2 is selected to have a low reactance at the signal frequency.

The forward bias for the emitter-base junction is provided by the voltage divider consisting of R_2 and R_3. R_3 is much larger than R_2 so that the base is made only slightly positive with respect to the emitter. R_1 is placed in the emitter circuit between the emitter and ground in order to stabilize the bias with temperature increases.

The signal applied between the emitter and base of the transistor varies the forward bias across the emitter-base junction which causes the number of electrons crossing the junction and reaching the collector to vary. The varying current flowing through the transistor reaches the parallel-resonant circuit consisting of L_3 and C_5. The current flows through L_3 to the tap on the coil and then through R_4 back to the positive terminal of the power supply.

Notice that the coil L_3 is tapped. The tap on L_3 is essentially at signal-ground potential. A voltage is induced in the lower end of L_3 which will be 180° out-of-phase with the voltage at the upper end of L_3. The voltage from the lower end of L_3 is fed through C_4 back to the base of the transistor. This voltage is fed back to neutralize or cancel any voltage that is fed from the collector of the transistor to the base through the collector-base capacity. This will prevent the stage from oscillating.

L_4 is inductively coupled to L_3, and since it has fewer turns than L_3 we have in effect a step-down transformer. Thus the input of the mixer transistor does not load the resonant circuit in the collector circuit of the rf amplifier.

In many ways the transistor rf amplifier is similar to the triode tube rf amplifier. Both may go into oscillation unless steps are taken to neutralize the feedback voltage through the device.

Transistors are also used as vhf rf amplifiers in TV receivers. A typical transistor vhf amplifier for a television receiver is shown in Fig. 15. Here you can perhaps see more closely the similarity between the transistor circuit and the triode tube circuit.

In Fig. 15, T_1 is a balun and its purpose once again is to match the balanced transmission line from the antenna to the unbalanced input of the rf amplifier.

In this circuit the combination of L_1 and C_1 form a parallel-resonant circuit. This circuit is resonant at approximately 41 MHz. The sound i-f frequency in the TV receiver is 41.25 MHz. The purpose of this circuit is to prevent any interference by a nearby station operating on 41 MHz from getting to the rf stage and on through into the sound circuits of the receiver.

The combination of C_2 and L_2 form a series-resonant circuit at 45.75 MHz. The picture i-f frequency in the TV receiver is 45.75 MHz. A series-resonant circuit offers a low resistance to signal frequencies near 45.75 MHz. Therefore this circuit will prevent interference from a nearby station operating on or near the video i-f from getting into the picture and causing interference.

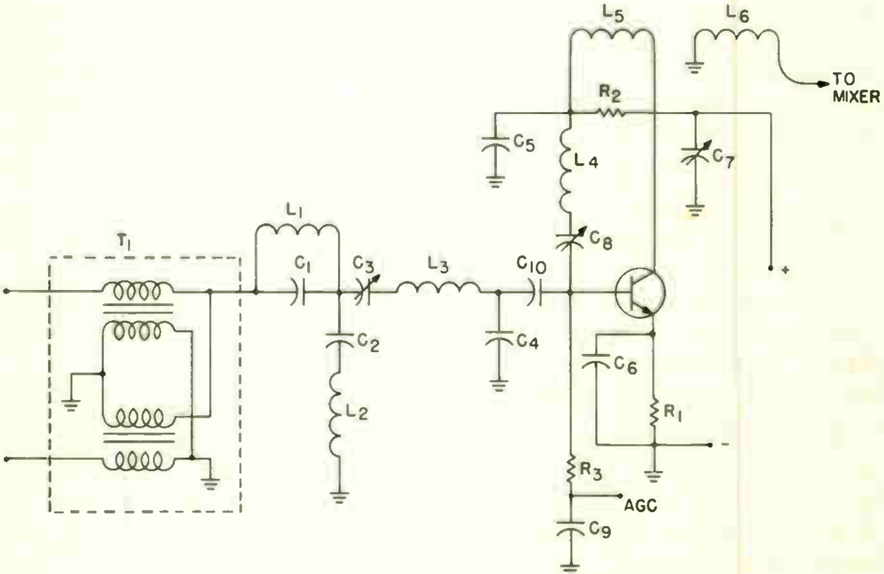


Fig. 15. Transistor vhf amplifier.

C_3 and L_3 form a series-resonant circuit which is tuned to the frequency of the desired TV station. The signal is fed through the capacitor C_{10} to the base of the transistor. The emitter of the transistor is at signal-ground potential, the resistor R_1 in the emitter circuit is bypassed by capacitor C_6.

The signal voltage fed between the base and emitter of the transistor causes the electron current through the transistor to vary and this causes the current flowing from the collector of the transistor and through L_5 to vary. The current from the collector flows through L_5, through R_2 and on to the + terminal of the power supply.

L_5 is inductively coupled to L_6; therefore a voltage will be induced in L_6. This voltage is fed to the mixer stage which follows the rf stage.

The signal at the lower end of L_5, that is the opposite end from the collector, is bypassed to ground through C_5. However, C_5 is not a perfect bypass and part of the signal is fed through L_4 and C_8 back to the base of the transistor. This is the neutralizing voltage which makes up for and cancels the signal fed across the collector-base capacity of the transistor back into the base circuit. Without this neutralizing circuit the rf stage would oscillate.

The forward bias for the transistor is applied through the resistor R_3 to the base. This bias circuit connects back to the automatic gain control circuit in the television receiver. The automatic gain control circuit regulates the gain of the rf stage automatically. In the case of a strong signal, the automatic gain control voltage reduces the gain of the rf stage, and in the case of a weak signal, it allows the stage to operate at maximum gain. You will go into automatic gain control circuits in detail later. Using an automatic gain control circuit to control bias across the emitter-base junction of the transistor will provide much more satisfactory results than applying a fixed forward bias across the junction.

FIELD-EFFECT TRANSISTOR AMPLIFIERS

As you learned earlier, the field-effect transistor combines many of the desirable characteristics of the vacuum tube, along with those of the transistor. Therefore it is reasonable that the field-effect transistor would make an excellent rf amplifier. Both the junction type and the insulated-gate type can be used as rf amplifiers.

Fig. 16 is a diagram showing a junction-type N channel field-effect transistor used as an rf amplifier.

In the circuit shown in Fig. 16, the source is connected to the negative side of the power supply and the drain to the positive side. A negative bias is applied to the gate through L_2 and R_1 from the agc terminal. The negative bias on the gate sets the current flow through the channel from the source to the drain of the transistor.

When a signal is received by the

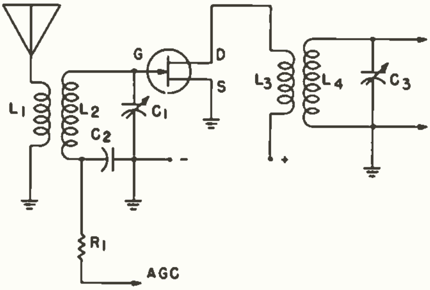


Fig. 16. An rf amplifier using a junction field-effect transistor.

antenna it causes a current to flow through L_1. L_1 is inductively coupled to L_2 and the voltage is induced in series with the turns of L_2. L_2 and C_1 form a series-resonant circuit which is tuned to the frequency of the incoming signal.

The induced voltage across L_2 is applied between the gate and ground in series with the negative bias applied to the gate. This voltage will add to or subtract from the gate bias depending upon the polarity of the signal voltage. The varying rf voltage will modulate the current flowing from the source to the drain, by varying the effective width and hence the resistance of the channel. Thus we have the signal voltage applied to the gate of the transistor causing substantial variations in the current flowing through the transistor.

The varying signal current from the drain of the transistor flows through L_3. L_3 is inductively coupled to L_4 and hence a signal voltage is induced in L_4. L_4 and C_3 form a series-resonant circuit which is tuned to resonance at the same frequency as L_2 and C_1. The output from the resonant circuit consisting of L_4 and C_3 can then be fed to another rf amplifier, to a mixer or to a detector.

The high input resistance of the junction-type field-effect transistor makes this transistor ideally suited for use as an rf amplifier. In operation, it actually resembles very closely a pentode tube. While the transistor we have shown in Fig. 16 is an N-channel transistor, a P-channel transistor can be used just as well. In this case the polarity of the voltages would be reversed and also a positive voltage would be applied to the gate in order to reverse bias the junction and prevent any current flow in the gate circuit.

There will be some reverse current flow across the junction in a junction-type field-effect transistor. This will have the effect of lowering somewhat the input resistance of the transistor. This can be overcome by the use of an insulated-gate field-effect transistor in a circuit such as shown in Fig. 17. The circuit here shows an N channel depletion-type insulated-gate field-effect transistor.

In the circuit shown, current flows from the negative side of the power supply through R_2 to the source of the transistor. It flows through the transistor to the drain and then through L_3 back to the positive side of the voltage source. The gate is connected to the negative automatic gain control voltage through L_2. The negative voltage applied to the gate will limit the width of the channel

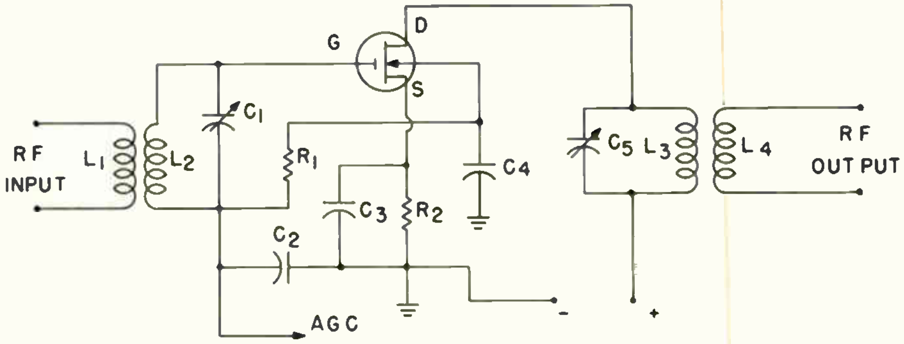


Fig. 17. An rf amplifier using an insulated-gate field-effect transistor.

and hence control the resistance of the channel.

In operation, the rf signal input is applied to L_1. This may be from another rf amplifier or directly from an antenna. The signal current flowing through L_1 induces a voltage in series with L_2. L_2 and C_1 form a series-resonant circuit. The resonant signal voltage is applied to the gate of the transistor and this voltage is applied in series with the negative agc voltage and hence varies the negative voltage on the gate at an rf rate. The varying signal voltage causes the resistance of the channel to vary and this causes the current flowing from the source through the transistor to the drain to vary. L_3 and C_5 form a parallel-resonant circuit. This high-impedance circuit develops a high signal voltage due to the varying current flowing through it. L_3 is inductively coupled to L_4 and the output from L_4 can be fed to another rf amplifier or to a mixer as it would be in the case of a superheterodyne receiver.

As in the case of the preceding circuit, a P-channel transistor could be used as well as an N-channel transistor. Also the enhancement type of insulated-gate transistors could be used. However, it is likely that most rf amplifiers using the insulated-gate field-effect transistors will be of the depletion type N channel transistors.

As mentioned previously, one of the disadvantages of the insulated-gate transistor is that they are easily damaged. Simply removing or inserting the transistor in the circuit when the voltages are applied could destroy the transistor due to high peak voltages built up in the gate circuit due to the very high resistance of the gate. Since the gate is actually insulated from the drain source by means of a layer of insulation the input resistance of the gate is extremely high. Pickup from a nearby power line can induce a high enough voltage in the gate to destroy the transistor if the gate circuit is open.

SELF TEST QUESTIONS

(k) What type of amplifiers are the rf amplifiers found in radio and television receivers?

(l) What type of resonant circuit is C_1 and L_2 in Fig. 10?

(m) What is the purpose of C_3 in the circuit shown in Fig. 10?

(n) What is permeability tuning?

(o) What is T_1 in the circuit shown in Fig. 13, and what purpose does it serve?

(p) Why are triode tubes often used as rf amplifiers in television receivers?

(q) Why does L_2, in Fig. 14, have fewer turns than L_1?

(r) What is the purpose of C_4 in the circuit shown in Fig. 14?

(s) In the circuit shown in Fig. 15 what are the combinations of L_1 and C_1 and L_2 and C_2 used for?

(t) Why must a negative voltage be applied to the gate of the junction field-effect transistor shown in Fig. 16?

(u) What is the primary advantage of the field-effect transistor in an rf amplifier circuit over the typical NPN or PNP transistor?

(v) Which of the two circuits, the one shown in Fig. 16 or the one shown in Fig. 17 has the least loading effect on the input circuit?

I-F Amplifiers

From the block diagram of the superheterodyne receiver which we have shown in Fig. 9, we see that the signal picked up by the antenna is amplified by an rf amplifier and then fed to a combination mixer and oscillator stage. In this stage the rf signal is mixed with a signal from a local oscillator. The local oscillator simply generates an rf signal which we use to mix with the incoming signal. The signal produced by the local oscillator is always a fixed frequency either above or below the frequency of the incoming signal. In most cases the oscillator is operated at a frequency above the frequency of the incoming signal.

Mixing the incoming rf signal with the locally generated signal produces two new signal frequencies in the mixer. It produces a signal equal to the sum of the frequency of the incoming signal plus the frequency of the oscillator and also a signal equal to the difference between the two frequencies. We use the difference signal as the intermediate frequency signal in a superheterodyne receiver. This signal is referred to as the i-f signal.

Since the frequency relationship between the incoming signal and the local oscillator is maintained constant, the i-f signal produced in the mixer will always have the same frequency. In other words, when the receiver is tuned to a signal of one frequency, for example a signal 1000 KHz, the oscillator might be operating at 1455 KHz. The difference between these two signal frequencies is 455 KHz and therefore this will be the i-f signal frequency. If we tune the receiver to a higher frequency, for example 1500 KHz, then the frequency of the local oscillator will also be increased so that when the rf and mixer stages are tuned to 1500 KHz, the local oscillator will be operating at 1955 KHz. Once again the difference frequency is 455 KHz. In other words, as long as we maintain the same difference between the incoming signal and the oscillator signal frequencies, the i-f signal frequency produced will be the same.

The advantage of a constant signal frequency for the intermediate frequency lies in the fact that we can design an amplifier with a higher gain when it is to be operated at a fixed frequency than we can if we have to be able to vary the frequency. Also, using a low frequency i-f gives us some advantages insofar as selectivity is concerned. We will go into this in detail later when you study superheterodyne receivers in more detail.

In this section of the lesson we are going to study some typical i-f amplifiers. Remember, even though we call the amplifiers intermediate frequency amplifiers, they are radio-frequency amplifiers because the signals they amplify are radio-frequency signals. However, they are different from the rf amplifiers you studied in the preceding section because they operate at a lower frequency, and also because once their frequency is set, it normally is not varied.

PENTODE I-F AMPLIFIERS

A typical pentode i-f amplifier is shown in Fig. 18. Notice that we have resonant circuits both in the input and the output of the stage, and that

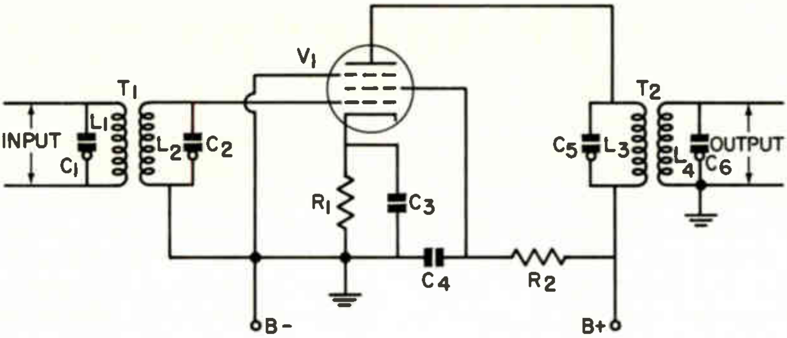


Fig. 18. A typical i-f amplifier using a pentode tube.

in many respects it resembles the pentode rf amplifier shown in Fig. 10.

In the circuit shown in Fig. 18, the input signal is obtained from the mixer output. In the output of the mixer we will have four signals. One signal will be equal to the frequency of the incoming signal, another signal will be equal to the frequency of the local oscillator. In addition, we have the two new signals produced by beating the incoming signal with the local oscillator signal. We have a signal equal to the sum of the two and a signal equal to the difference between the two. C_1 and L_1 form a parallel-resonant circuit which is resonant at a frequency equal to the difference between the local oscillator frequency and the incoming signal frequency. Thus, the parallel-resonant circuit acts as a high impedance at the difference signal frequency and a comparatively high signal voltage of this frequency is developed across it.

L_1 is inductively coupled to L_2. This causes a signal voltage to be induced in L_2. L_2 and C_2 form a series resonant circuit, and they also are tuned to the difference frequency, which from now on we will call the i-f frequency. In the series-resonant circuit we have a resonant voltage step-up, and this voltage is applied to the grid of V_1, and to the cathode through C_3. C_3, the cathode bypass is chosen so that it has a low reactance at the signal frequency.

The i-f signal applied between grid and cathode of V_1 causes the plate current flowing through the tube to vary and this varying plate current is fed to the parallel-resonant circuit consisting of L_3 and C_5. A high signal voltage is developed across the high impedance parallel-resonant circuit. L_3 is inductively coupled to L_4 and the combination of L_4 and C_6 form a series-resonant circuit which is also tuned to the i-f frequency. From the output, the voltage is fed to another i-f amplifier or to the second detector which separates the intelligence signal on the carrier from the carrier.

As in the rf amplifier the screen of the pentode tube is operated at signal ground potential by means of a bypass capacitor C_4 which has a low reactance at signal frequency. A positive dc voltage is applied to the screen of the tube through the resistor R_2. Normally the screen of the tube will be operated at a lower voltage than the plate and R_2 is chosen so that the voltage drop across it, when subtracted from the plate voltage, will provide the correct screen voltage for the tube.

In some circuits the suppressor

grid, the grid nearest the plate, is tied directly to the cathode of the tube. However, tieing the suppressor to ground will often introduce a small amount of degeneration in the stage and improve the stability of the stage. With modern pentode tubes there is such a high voltage gain in the stage, that even though the voltage fed from the plate of the tube through the tube, back to the grid of the tube is very small, it is possible that this voltage might be high enough to cause oscillation unless steps are taken to prevent it.

In some amplifiers you will find that the cathode of the tube is not bypassed. Leaving the cathode unbypassed again introduces some degeneration as it did in the case of audio amplifiers and this will tend to stabilize the stage and further prevent the stage from going into oscillation.

We mentioned earlier that the i-f amplifier is operated at a fixed frequency. Once the receiver is set up, the resonant frequency of the tuned circuits is not changed as you tune from station to station. When the receiver is set up, the various resonant circuits are all adjusted to resonate at the i-f frequency. This is usually accomplished by feeding a signal from an instrument called a signal generator into the i-f amplifier. The signal generator is set to the intermediate frequency and then the various resonant circuits are adjusted for maximum output from the i-f amplifier. The coupling between the coils is adjusted by the manufacturer so that when the various circuits are tuned for maximum output the required bandpass will be obtained. It is possible to do this in radio receivers because the bandwidth required in radio reception is comparatively narrow. In television receivers, however, the i-f amplifier presents special problems and alignment methods other than peaking the transformers or coils at one frequency must be used.

In the early days of radio, triode i-f amplifiers were used, but since the development of the pentode tube, the triode tube has not been used for this purpose. You can get a higher gain with a pentode i-f amplifier than with a triode, and in addition the pentode does not require neutralization.

TRANSISTOR AMPLIFIERS

A typical transistor i-f amplifier is shown in Fig. 19. Notice that this circuit is practically identical to the

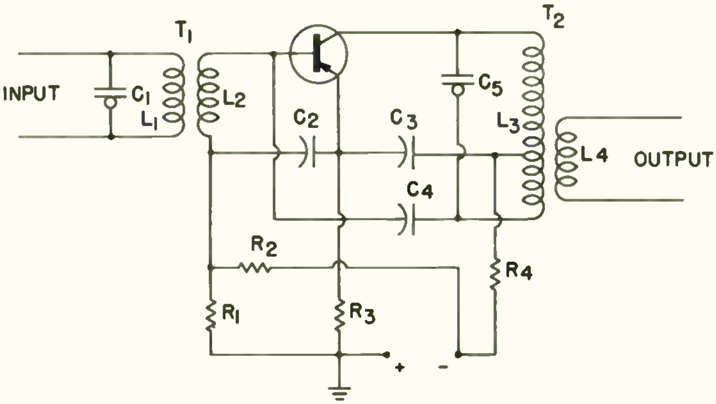


Fig. 19. A typical transistor i-f amplifier using a PNP transistor.

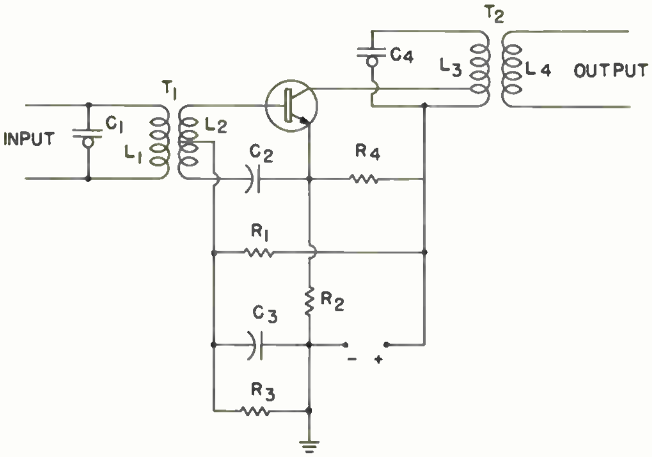


Fig. 20. Transistor i-f amplifier using NPN transistor.

circuit of the rf amplifier shown in Fig. 14.

In Fig. 19, C_1 and L_1 form a parallel-resonant circuit and would be in the collector circuit of the mixer stage. L_1 is inductively coupled to L_2. L_2 has fewer turns than L_1 so that we have a step-down transformer to match the low input resistance of the transistor circuit to the high resistance of the parallel circuit. The signal is applied to the base of the transistor and to the emitter through C_2. The i-f signal current from the collector is fed to the parallel resonant circuit which consists of L_3 and C_5. L_4, which has fewer turns than L_3, is inductively coupled to L_3 so that a signal current will be induced in L_4. The output from L_4 would probably be connected to another transistor i-f amplifier or to a detector stage. As in the rf stage shown earlier, C_4 provides neutralization and feeds a signal back into the base which is 180° out-of-phase with the signal fed from the collector to the base through the transistor.

Forward bias for the transistor is provided by the voltage divider network consisting of R_1 and R_2. As in the previous circuits, R_3 is put in the circuit for bias stabilization, to prevent thermal runaway of the transistor.

Another transistor i-f amplifier is shown in Fig. 20. This amplifier uses an NPN transistor whereas the one shown in Fig. 19 uses the PNP transistor. In addition to the different transistor types, the method of obtaining neutralization is somewhat different. Notice the resistor in the emitter circuit, R_2. This resistor is not bypassed and therefore a signal voltage will be developed across this resistor. This signal voltage is fed through C_2 into the lower end of the coil L_2. The center tap of L_2 is at signal ground potential, because C_3 has a low reactance at the signal frequency. The lower end of L_2 is inductively coupled to the upper end so that a voltage is induced in the upper end of the coil 180° out-of-phase with the signal fed to the lower end through C_2. This voltage is fed to the base and will neutralize any signal voltage fed from the collector back into the base through the transistor itself.

Notice that the collector is connected to a tap on the coil L_3. The output resistance of the transistor is comparatively low and by feeding it to a tap on the coil in this manner we prevent loading of the parallel resonant circuit made up of L_3 and C_4. This prevents loading of the resonant circuit which in turn would cause a reduction in the selectivity in the circuit.

Field-effect transistors can also be used as i-f amplifiers, but since they are considerably more expensive than the PNP and NPN types they have not been widely used in this application.

VIDEO I-F AMPLIFIERS

Television receivers are superheterodyne receivers just like radio receivers. However, the rf, mixer and oscillator stages operate at higher frequencies than regular receivers designed for reception on the standard broadcast band.

The i-f amplifier used to amplify the picture signals is called a video i-f amplifier. A video i-f amplifier differs from a sound i-f amplifier inasmuch as it operates at a much higher frequency and must have a much wider bandwidth. This is due to the fact that a wide range of signals is required in order to reproduce a TV picture. Some large areas may be reproduced by comparatively low frequency signals, but the fine detail in a picture is reproduced by comparatively high-frequency signals. The video i-f amplifier must be able to pass the video i-f carrier and the sidebands which contain the video signal. Also, in color TV receivers they must pass an additional signal called the color subcarrier. This signal carries the color information in the picture. In addition, modern superheterodyne TV receivers must be capable of passing the sound i-f signal through at least part of the video i-f amplifier. The sound i-f signal differs from the picture i-f signal by 4.5 megahertz. Therefore the video i-f amplifier must be capable of at least passing with some amplification the sound i-f signal which will be 4.5 MHz lower in frequency than the video i-f carrier frequency.

You'll study video i-f amplifiers later, but here we want you to get some general idea of what the circuit looks like and the problems involved.

A typical video i-f amplifier using a pentode tube is shown in Fig. 21.

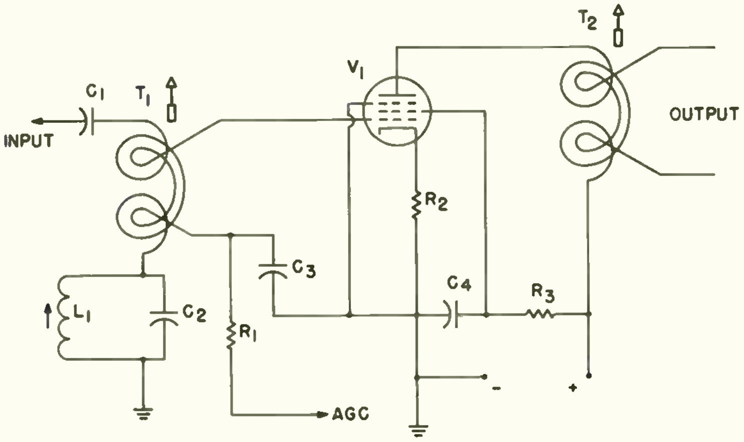


Fig. 21. A pentode video i-f amplifier.

This is typical of the circuits you will find in the first video i-f amplifier of a color TV receiver or of a black and white TV receiver. The input signal is fed to the i-f amplifier from the mixer. It is fed through the capacitor C_1 to the primary of T_1. T_1 is the input i-f transformer and the coils are bifilar wound. This means that the coupling between the coils is extremely tight. The arrow above the two coils indicates that there is an iron slug inside the coils which can be adjusted to tune the two coils to a particular frequency.

An example of how a bifilar wound transformer is constructed was shown in Fig. 8. Notice that the two windings are interlaced to provide very tight coupling between the primary and secondary windings of the transformer.

The combination of L_1 and C_2 form a parallel-resonant circuit. This circuit is resonant at a frequency of 47.25 MHz. This parallel-resonant circuit is referred to as an adjacent channel sound trap. When your TV receiver is tuned to channel 4, for example, if you happen to be near enough to pick up a signal from another station operating on channel 3, the sound signal from the channel 3 station might get through the rf and mixer stages and could cause some interference in the picture. By inserting the parallel-resonant circuit in series with the primary of T_1, if there is any signal current from the channel 3 sound flowing in the circuit, almost all will be dropped across the high impedance of this parallel-resonant circuit. Very little will be fed from the primary to the secondary of T_1.

The grid of the tube is fed to the automatic gain control circuit through R_1. The automatic gain control will provide a negative voltage for the grid of the tube. This voltage will vary in amplitude depending upon the strength of the signal received. If the signal is very strong, a rather high negative voltage will be fed to the grid of V_1. This will reduce the gain of the stage and prevent overloading in following stages. On the other hand, if the signal is weak, the negative voltage fed to the grid of V_1 will be quite low so that the tube will operate at its maximum gain.

T_2 is another bifilar wound i-f transformer. Again, the primary and secondary coils are very tightly coupled.

You might notice that there is no capacitor in the plate circuit of V_1. In spite of this, we have a parallel-resonant circuit in the plate circuit of V_1. You might wonder how this is so, but remember that there is a certain capacity in the tube itself. There is capacity between the plate and cathode and this is in effect electrically across the primary of T_2. This capacity along with the wiring capacity in the circuit is all the capacity we need at the frequencies involved to form a parallel-resonant circuit along with the primary winding of T_2. Video i-f amplifiers usually operate in the 40 MHz region, and at these high frequencies only a small amount of capacity is needed in a resonant circuit.

A typical transistor video i-f amplifier is shown in Fig. 22. This i-f amplifier is the second video i-f amplifier taken from a portable TV receiver. The input signal is received from the first video i-f amplifier and coupled from L_1 to L_2. L_2 has fewer turns than L_1 in order to match the transistor input circuit. C_1 is placed in the circuit to prevent L_2 from shorting out the forward bias across the emitter-base junction of the transistor. The for-

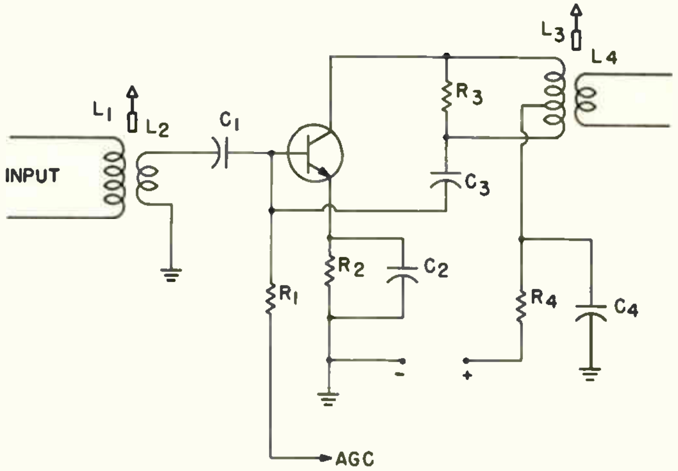


Fig. 22. A transistor video i-f amplifier.

ward bias is applied to the base through R_1. Again, this bias is obtained from the agc system, and is varied to vary the gain of the transistor depending upon the strength of the signal being received.

The coil L_3, which is in the collector circuit of the transistor, along with the transistor capacity and the wiring capacity, form a parallel-resonant circuit. The arrow of the coil indicates that the circuit can be tuned by means of a slug which moves in and out of L_3. Notice that the collector voltage is fed to a center tap on the coil. The center tap is held essentially at ground potential by the capacitor C_4. A voltage is induced in the lower half of L_3 which is 180° out-of-phase with the voltage in the upper half. The voltage from the lower half is fed through C_3 back into the base circuit in order to provide neutralization and to cancel out any signal fed through the transistor from the collector to the base.

The resistor R_3, which is connected across L_3, is a loading resistor. The purpose of this resistor is to load the resonant circuit in order to help get the broad frequency response required of a video i-f amplifier.

L_4 is inductively coupled to L_3 and feeds the next video i-f amplifier.

In aligning a video i-f amplifier such as shown in Fig. 22, L_1 is not tuned to the same frequency as L_3. By tuning the resonant circuits to different frequencies we broaden the response of the amplifier. For example, the resonant circuit in which L_1 is located may be tuned as shown by curve A in Fig. 23. At the same time L_3 and its circuit might be tuned as shown in curve B. The overall response produced by the two amplifiers may then look like curve

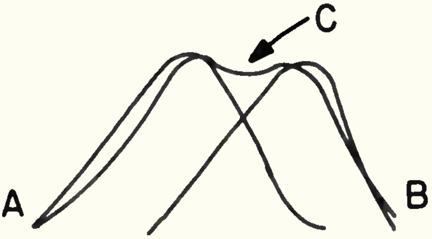


Fig. 23 Response of curves A and B together may give overall response like C.

C which has a wider bandwidth than either curve A or curve B. You will study video i-f amplifiers in detail later and learn more about how the various resonant circuits are adjusted for resonance.

SELF TEST QUESTIONS

(w) What determines the i-f frequency in a receiver?

(x) Why can we usually operate an i-f amplifier at higher gain than an rf amplifier?

(y) Why is the cathode resistor in some pentode i-f amplifiers left unbypassed?

(z) In the circuit shown in Fig. 20, why is the collector connected to a tap on L_3?

(aa) Where is the neutralization for the transistor in the circuit shown in Fig. 20 obtained?

(ab) What is the chief difference between the video i-f amplifier in a television receiver and the sound i-f amplifier in a radio receiver?

(ac) Why is there no capacitor across the primary winding of T_2 in the circuit shown in Fig. 21?

(ad) What purpose does R_3 in Fig. 22 serve?

(ae) What purpose does C_3 in Fig. 22 serve?

Radio-Frequency Power Amplifiers

So far the rf amplifiers we have been discussing are the types found in radio and television receiving equipment. They are voltage amplifiers. They are used to build the weak signal voltage to a reasonably high value before the signal is fed to a detector to extract the intelligence that has been used to modulate the carrier. In radio and television transmitters and in other industrial applications rf power amplifiers are used. RF power amplifiers differ from voltage amplifiers in a number of respects. Not only are the tubes generally much larger than those used in voltage amplifiers, but also the circuit configurations differ in several respects from those used in voltage amplifiers.

A TRIODE POWER AMPLIFIER

Although triode tubes are not very frequently used as rf voltage amplifiers except in the vhf region, they are quite widely used as power amplifiers. Many high-power transmitters today use triode rf power amplifiers.

Schematic diagrams of two triode rf power amplifiers are shown in Fig. 24. Since there are several differences between these two circuits we'll look at the circuits one at a time.

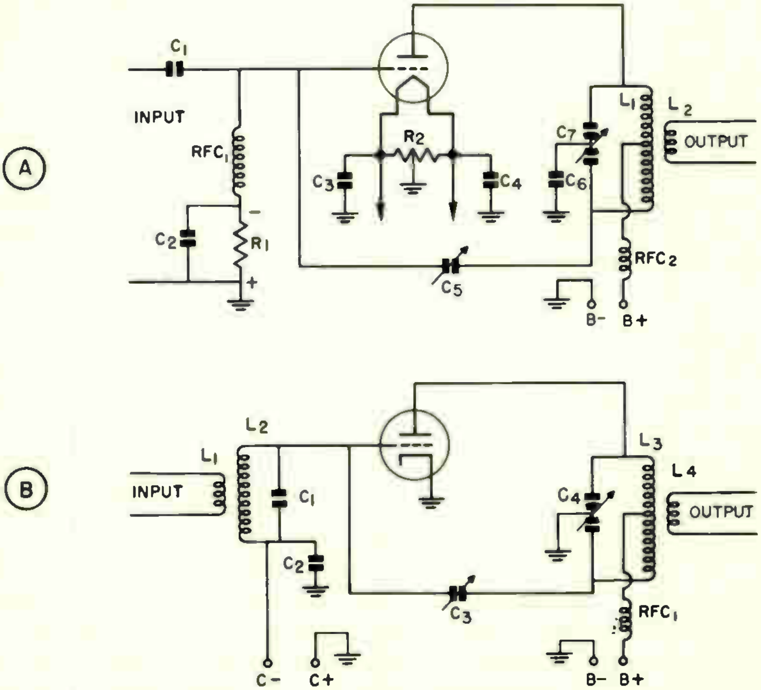


Fig. 24. Schematic of two triode power amplifiers.

In the circuit shown in Fig. 24A we have shown a filament-type tube. This type of tube is frequently found in transmitting applications because a solid tungsten filament or a thoriated tungsten filament will stand up better than an oxide-coated cathode at the high voltages usually used in transmitting tubes. In the circuit shown in Fig. 24B we have shown a cathode-type triode tube so that you will see the difference between the two types.

Examining the grid circuit of the diagram shown in Fig. 24A, you'll see that connected between the grid of the tube and ground we have a coil called a radio-frequency choke. This is abbreviated RFC on the diagram. Also connected between this choke and ground we have a resistor R_1. Power amplifiers are normally operated as class C amplifiers. This means that the input signal drives the grid of the tube positive so that electrons flow from the filament of the tube to the grid. These electrons will strike the grid and then flow from the grid through the rf choke to the parallel combination of R_1 and C_2. Some of the electrons will flow through R_1 to ground, but most of them will charge C_2. During the portion of the cycle when the grid is not drawing current, C_2 will discharge through R_1. The time constant of R_1 and C_2 is selected so that C_2 does not appreciably discharge between cycles of grid current. R_1 is selected so that the average grid current provides the bias required for the tube. Usually for class C operation, this is somewhere between two and four times cut-off bias voltage.

Notice the bypass capacitors and the tapped resistor in the filament circuit. Each side of the filament is bypassed to ground, and a tapped resistor is connected across the filament, and the center tap of this resistor is grounded. Sometimes instead of using a tapped resistor of this type, the filament winding of the transformer used to supply the voltage to heat the tube is center-tapped and the center tap is grounded.

The filament of a transmitting tube is rather heavy, and as a result can be operated from ac. The temperature of the filament changes so slowly that there is no heating and cooling of the filament as the ac voltage goes through its cycle.

With the high bias on the tube, plate current will flow through the tube in a series of pulses. There will be a pulse of plate current each time the input signal drives the grid sufficiently in a positive direction to overcome the bias. Because the grid is driven positive, the peak current reached during each pulse will be high, but because the operating bias on the tube will be substantially beyond cutoff bias, plate current will flow for less than one half of each cycle.

In the plate circuit of this stage, we have a parallel resonant circuit. Notice that the coil L_1 is tapped, and the center tap is connected through another radio-frequency choke (usually called an rf choke) to B+. The B+ voltage applied to the plate of the tube is thus applied through the choke and half of L_1. Capacitor C_7 is a variable capacitor called a split stator capacitor. You will remember that a variable capacitor has two separate plates, one set that is stationary, called the stator, and the other set that rotates, called the rotor. In a split-stator type capacitor there are two sets of stator plates, which are insulated from each other. The rotor consists of two separate sets of plates, one for each set of stator plates, but the rotor plates are electrically connected together. The rotor is operated at signal ground potential by grounding it through C_6 and the stators are connected to the ends of L_1.

The parallel resonant circuit in the plate circuit of the tube is more or less shock-excited by the pulses of plate current received from the tube. The pulse of the plate current sets up circulating currents in the tank circuit. These pulses from the tube are more or less smoothed out by the tank circuit so that the current circulating back and forth in the resonant circuit is a sine wave.

Since the tube used in this circuit is a triode tube, there will be energy fed from the plate of the tube back to the grid circuit. Because a power amplifier develops considerable power in the plate circuit, there will be enough energy fed back into the grid circuit to result in oscillation. This oscillation is overcome by feeding a signal from the tank circuit through C_5 back into the grid circuit of the tube. Notice that the plate of the tube connects to one end of the tank circuit and C_5 connects to the other end. The voltage at the two ends of the tank circuit will be of opposite polarity. Therefore, the signal fed through C_5 back into the grid circuit is of opposite polarity to the signal fed from the plate to the grid circuit through the tube capacity. C_5 is usually an adjustable capacitor that can be adjusted to feed exactly the same amount of signal into the grid circuit as is fed through the tube capacity. C_5 is called a neutralizing capacitor. It is used to feed back energy into the grid circuit to neutralize or cancel the energy fed back into the grid circuit through the tube.

The output signal is taken from the tank circuit by inductively coupling another coil, marked L_2 on the diagram, to L_1.

When a tube is used in a circuit of this type where its bias is developed by the grid current flowing through the grid resistor, we say the tube is self-biased. This type of bias is entirely satisfactory when the stage is operating properly and when the normal signal drive is applied to the input. However, if a defect develops in a preceding stage so that no signal is applied to the input, the grid of the tube will not be driven positive and there will be no current flow. Capacitor C_2 will discharge through R_1 so that the bias applied to the tube will disappear. Once the bias disappears there will be a very high current flow from the filament to the plate of the tube and unless there is some safety measure incorporated in the circuit so that the circuit will be opened when the current goes beyond a certain level, the current will rise to such a high value that the tube will be destroyed.

In the circuit shown in Fig. 24B we have tuned circuits in the input and output circuits. Coil L_1 is inductively coupled to L_2 and its energy fed into L_2. L_2 and C_1 form a series resonant circuit. Here, instead of using self-bias, a fixed bias voltage is applied to the grid circuit of the tube. Notice that the negative terminal of the C battery or C bias supply connects to the coil, and through the coil to the grid. The positive terminal of the C supply is grounded. Sometimes you'll find the bias connections on the diagram labeled C- and C+ as in Fig. 24B and on other occasions you'll find them labeled bias.

The resonant circuit in the plate circuit of this stage is the same as the circuit shown in Fig. 24A. Again, the stage is neutralized by feeding energy from the tank circuit through a capacitor (C_3) back into the grid circuit of the tube.

In some triode power amplifiers you'll find a combination of fixed bias and self bias. In this type of circuit the two types of bias shown in Fig. 24 are incorporated into a single circuit. This is done by selecting a value of resistor in the grid circuit somewhat smaller than what is needed to develop the full bias required by the tube. The remainder of the bias is supplied by a separate bias power supply. For example, if a tube requires a bias of 100 volts for class C operation, a resistor might be put in the grid circuit that would develop 50 volts bias and then a fixed power supply used to provide the other 50 volts. The advantage of this arrangement is that the bias is somewhat self-regulating. In other words if the grid current increases, the bias will increase and tend to prevent overdriving the tube. At the same time, the fixed bias would also protect the tube if the preceding stage develops a defect so that the signal drive is not supplied to the grid of the tube.

TETRODE POWER AMPLIFIERS

Tetrode power amplifiers have two big advantages over the rf triode power amplifiers. Perhaps the greater advantage lies in the fact that a tetrode has a very high power sensitivity. This means that you need only a small input signal to drive the tube hard enough to produce a rather large signal in the output. Thus the power gain in a tetrode rf power amplifier is much greater than in a triode power amplifier, because a substantial amount of driving power is usually required to drive a triode.

The second big advantage of a tetrode power amplifier is the fact that the screen grid effectively shields the grid of the tube from the plate. With careful circuit design it is usually possible to design a circuit that does not require neutralization. This is a big advantage if a power amplifier is to be used over a wide frequency range. In a triode power amplifier, if you have occasion to change the frequency at which the amplifier is operating, you often have to readjust the setting of the neutralizing capacitor. However if a tetrode stage can be operated without neutralization, this problem is not encountered. Of course, in a radio broadcast transmitter that is designed to operate on one specific frequency, neutralizing the triode doesn't present any great problem, and once it is neutralized you do not have to re-neutralize it unless you change the tube. However, in many communications applications, it is necessary to have transmitters that can be operated on a number of different frequencies. In such a case, a tetrode tube that does not need neutralization is quite advantageous.

The tetrode tubes used in modern power amplifiers are beam power tubes. You will remember that a beam power tube is a tube made so that the cathode emits electrons in two streams or beams from opposite sides of the cathode. The electrons are further focused into a beam by means of beam-forming plates which are connected inside the tube to the cathode of the tube. Although you might actually consider the beam-forming plates as separate elements, the general practice is to ignore them when counting the tube elements so the tube is considered to be a tetrode or four-element tube.

A schematic diagram of a tetrode rf power amplifier is shown in Fig. 25. Notice that we have a resonant circuit in the input. Again, this tube circuit uses self bias; the bias needed to operate the tube in the Class C amplifier is developed

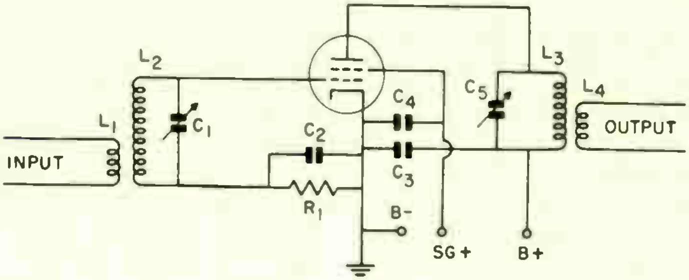


Fig. 25. A tetrode rf power amplifier.

across the parallel combination of R_1 and C_2 by the grid current. Again, grid current flows because on the positive half cycle the signal drives the grid positive and electrons are attracted to the grid.

A parallel resonant circuit is used in the plate circuit, and the output is taken by inductively coupling L_4 to L_3.

The screen grid of the tube is operated with a positive voltage applied to it. Sometimes this voltage is obtained from a separate power supply or from a tap on the main power supply. Sometimes a dropping resistor is connected between the plate supply and the screen grid of the tube in order to drop the screen voltage to a value lower than the plate voltage.

A push-pull tetrode power amplifier is shown in Fig. 26. Here notice that the circuit configuration is quite similar to the push-pull circuits used in audio work with the exception of the resonant circuits used in the grid and plate circuits of the tube. Notice that split stator tuning capacitors have been used in both the input and the output circuits. Again, because the feedback from the plate of the tube to the grid of the tube is low due to the shielding effect of the screen, neutralization is not required. However, sometimes you will find tetrode power amplifiers using neutralization.

Pentode rf power amplifiers are sometimes used, but they are not nearly as common as tetrode power amplifiers. The circuits used for

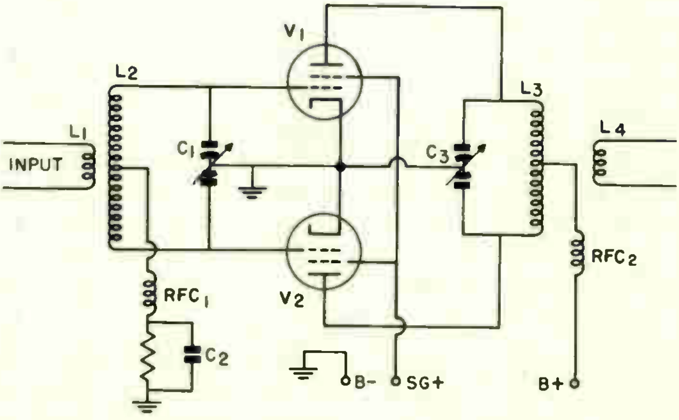


Fig. 26. A push-pull tetrode rf power amplifier.

pentode tubes are similar to those used for tetrodes. The suppressor grid of the pentode tube is usually connected to B-.

TRANSISTOR POWER AMPLIFIERS

A few years ago there were relatively few transistor rf power amplifiers because the rf power that could be generated by transistors was quite limited. However, a great deal of progress has been made in transistor design and manufacture and now there are many transistor rf power amplifiers in use. Of course, there are no transistors available that can develop the very high rf powers that vacuum tubes can develop, but low and medium power rf transistors are available.

Transistor power amplifiers may be used in either the common-emitter or common-base circuits. The common-emitter circuit is more stable, but at very high frequencies the emitter lead inductance may restrict the power capability of the transistor. In this case the common-base circuit may provide a higher power gain, but it will be more unstable than the common-emitter circuit.

Transistor rf power amplifiers may be operated as Class A, Class B or Class C amplifiers. Class A amplifiers provide extremely good linearity but the efficiency is low. This type of power amplifier is used only when the power requirements are quite low. A Class B power amplifier will provide a higher power gain and better efficiency. Of course, a Class C power amplifier will provide the best efficiency, but the harmonic output from a Class C power amplifier will be quite high. The tank circuits used with Class C power amplifiers are designed to offer a high impedance to the harmonics and a low impedance to the fundamental frequency.

Biasing Methods.

For Class A bias on a transistor power amplifier, we must have a forward bias across the emitter-base junction as in the case of transistor voltage amplifiers. For Class B bias, the bias across the emitter-base junction of the transistor is zero. For Class C bias, we must have a reverse bias across the emitter-base junction so that current will flow through the transistor only on the peak of the rf cycle. That overcomes the reverse bias and drives the emitter-base junction into the conduction region. As in the case of vacuum-tube Class C amplifiers, current will flow through the transistor for less than half a cycle.

Two typical circuits for developing Class C bias for a transistor power amplifier are shown in Fig. 27. In the circuit shown in Fig. 27A, the incoming rf signal drives the

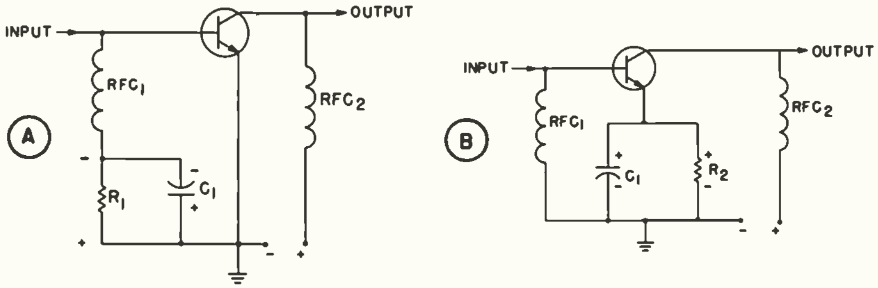


Fig. 27. Two methods of producing bias for Class C power amplifiers.

base of the transistor positive and electrons leave the base and flow through the rf choke and charge the capacitor C_1 with the polarity shown. Some of the electrons flow through R_1 to ground developing a voltage drop across this resistor having the polarity shown.

During the portion of the rf cycle when the transistor is not conducting, C_1 discharges through R_1 maintaining the reverse bias across the emitter-base junction essentially constant.

Another method of obtaining Class C bias is shown in Fig. 27B. In this circuit, when the input signal drives the base positive, current flows through the resistor R_2 to the emitter, across the emitter-base junction of the transistor, across the base and the base-collector junction and then through the rf choke RFC_2 back to B+. The electrons flowing through R_2 will charge capacitor C_1 with the polarity shown. During the portion of the cycle when the base is not driven positive by the rf signal, C_1 will discharge through R_2 maintaining the emitter positive with respect to ground. Thus the emitter will be positive with respect to the base and will have a reverse bias across the emitter-base junction so there will be no current flow through the transistor.

Typical Circuits.

A typical Class C transistor rf power amplifier is shown in Fig. 28. In this circuit the biasing method shown in Fig. 27B is used to provide a reverse bias across the emitter-base junction.

The rf signal is fed into the input and on the positive half of the cycle the rf signal overcomes the reverse bias across the emitter-base junction and electrons flow through the transistor. The choke in the collector circuit completes the dc current path through the transistor. The rf signal is fed to the output network consisting of C_2, C_3, L_1 and L_2. C_2 is adjusted for resonance and C_3 is adjusted to obtain the desired loading.

When more power is required from an rf power amplifier than can be obtained from a single transistor, two or more transistors can be used either in push-pull or in parallel. In push-pull operation transformers must be used for proper input signal phase. This works out quite satisfactorily at lower i-f frequencies, but at very high frequencies it is difficult to build transformers which provide the required impedance

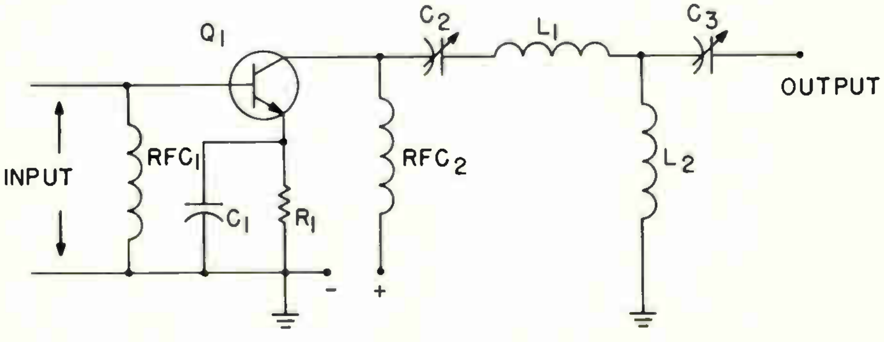


Fig. 28. A Class C transistor power amplifier.

transfer. Therefore parallel operation of transistors is generally preferred at vhf over push-pull operation.

In Fig. 29 we have shown a schematic diagram of two transistors operated in parallel. If additional power is required, a third parallel transistor in an essentially identical circuit could be added.

Previously we mentioned the effect of emitter-lead inductance at vhf. The effect of this inductance is tuned out by the capacitors C_3 and C_4.

In a circuit of this type, it is desirable to have transistors with matched characteristics in order to insure that each transistor will pick up half of the load.

To check the operation of the transistors to be sure that each is handling half the total current, we measure the voltage across R_1 and the voltage across R_2. The voltages across these two resistors should be equal; this would indicate each transistor is picking up half of the load.

SELF TEST QUESTIONS

(af) What is the purpose of C_5 in Fig. 24A?

(ag) Why is it possible to operate the filament of the triode tube shown in Fig. 24A from ac power?

(ah) How are the pulses of current that flow through a Class C amplifier stage smoothed into a sine wave?

(ai) What are the two big advantages of the tetrode power amplifier over the triode power amplifier?

(aj) What type of bias is placed across the emitter-base junc-

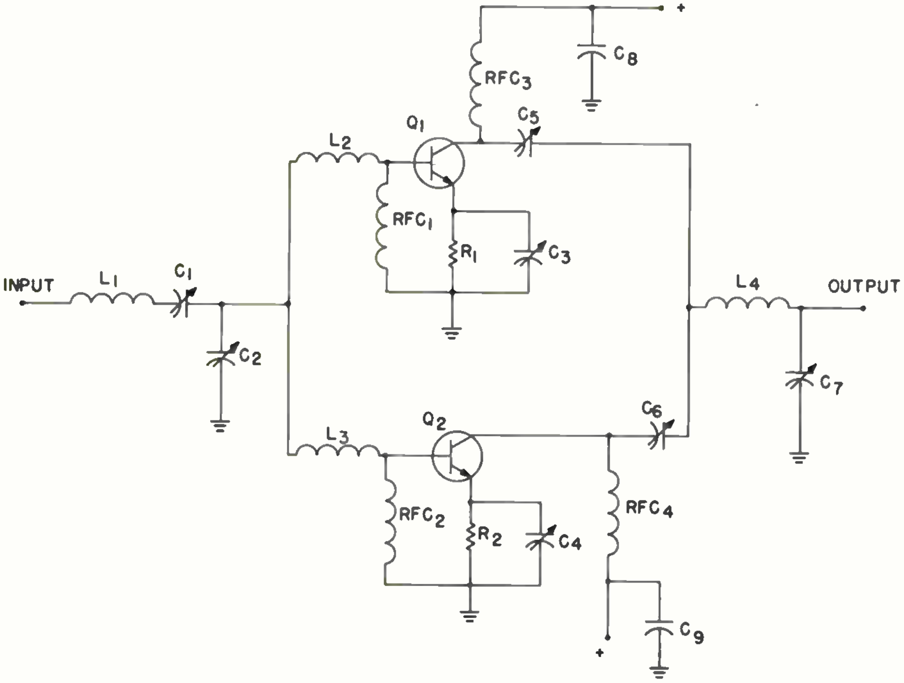


Fig. 29. A high-frequency power amplifier using two transistors in parallel.

tion of a transistor operated as a Class C power amplifier?

(ak) Across what parts is Class C bias developed in the circuit shown in Fig. 27A?

(al) What purpose do the capacitors C_3 and C_4 in the circuit shown in Fig. 29 serve?

ANSWERS TO SELF TEST QUESTIONS

(a) The basic difference is in the load found in the rf amplifier. It is usually some type of resonant circuit.

(b) The basic difference is how the voltage is applied to the coil and capacitor in the resonant circuit. If the voltage is applied to the coil and capacitor in series, it is a series-resonant circuit, but if it is applied to the coil and capacitor in parallel, it is a parallel-resonant circuit.

(c) Sideband frequencies are frequencies above and below the carrier frequency produced when we add the intelligence to be transmitted to the carrier frequency.

(d) The bandwidth of a resonant circuit is the band of frequencies that will be passed or amplified by the circuit with a gain equal to at least 70.7% of the gain obtained at the resonant frequency of the circuit.

(e) On the L-C ratio of the resonant circuit and on the Q of the resonant circuit.

(f) By loading the circuit with a suitable resistance.

(g) Critical coupling is the point at which maximum signal transfer occurs from one coil to another. This will occur when all the flux lines produced by one coil cut the turns of the other coil.

(h) When we speak of over-coupling we mean that the coils are coupled together beyond the critical coupling point. It results in some drop in output and produces a so-called double-hump response curve.

(i) The moisture and dust particles will introduce resistance into the circuit and lower the Q of the circuit. This will tend to reduce the output from the resonant circuit and also reduce the selectivity.

(j) At the high frequencies used in the rf section of a television receiver, moving a wire may change the inductance or capacitance in a resonant circuit sufficiently to upset the performance of that circuit. This is particularly true of the coils and leads used in conjunction with the high vhf channels in a TV tuner. It is even more true of the parts and leads in a uhf tuner.

(k) The rf amplifiers in radio and television receivers are Class A voltage amplifiers.

(l) C_1 and L_2 in Fig. 10 form a series-resonant circuit.

(m) C_3 is a screen bypass capacitor. It is chosen so that it has a low reactance at the signal frequencies amplified by the stage. Therefore as far as the screen is concerned, it is essentially connected to ground at signal frequencies. This permits the screen to act as an effective shield between the plate and grid of the tube, to prevent feedback from the plate to grid that could cause oscillation.

(n) Permeability tuning is a tuning system where the inductance of the coils is varied by moving a powdered iron slug in and out of the coil. The resonant frequency of the circuit is varied by varying the inductance of the coil rather than by changing the capacity of the tuning capacitor.

(o) T_1 is a balun. It is used to match the balanced transmission line, which has an impedance of 300 ohms, to the unbalanced input of the rf stage, which has an input impedance of 75 ohms. Thus the transformer matches a balanced circuit to an unbalanced circuit, at the same time it matches a 300-ohm circuit to a 75-ohm circuit.

(p) Triode tubes generate a lower internal noise than pentode tubes. Low noise level is extremely important in the rf stage of TV receivers, particularly in the reception of the high-band vhf TV channels.

(q) The combination of L_1 and L_2 form a transformer because L_1 is inductively coupled to L_2. L_1 along with C_1 form a series-resonant circuit. A step-down transformer is used to feed the signal to the input of the transistor because the transistor has a comparatively low input resistance. When using a step-down transformer (having fewer turns on L_2 than on L_1), loading of the resonant circuit can be kept to a minimum. Excessive loading of the resonant circuit would reduce the selectivity of the resonant circuit.

(r) C_4 is used to feed a small amount of signal from the output back into the base of the transistor. The energy fed through C_4 is 180° out-of-phase with the signal fed from the collector back to the base through the transistor itself. The signal fed through C_4 cancels the signal fed internally through the transistor. C_4 is a neutralizing capacitor and prevents the stage from going into oscillation.

(s) L_1 and C_1 form a parallel-resonant circuit. They prevent undesired signals in the sound i-f frequency region from getting to the rf amplifier. C_2 and L_2 form a series-resonant circuit. Since they have a low impedance they bypass the signals around 45 MHz. 45.75 MHz is the picture i-f signal frequency. The trap prevents interfering signals from stations operating at or near this frequency from reaching the rf amplifier.

(t) A negative voltage is applied to the gate to prevent electrons from flowing to the gate. This would cause current to flow in the gate circuit and lower the input resistance of the transistor.

(u) The field-effect transistor has a very high input resistance. Therefore the transistor has very little or no loading effect on the resonant circuit which permits a high degree of selectivity. In addition, very high gains are possible with the field-effect transistor.

(v) The circuit shown in Fig. 17. This circuit makes use of an insulated-gate field-effect transistor. There will be no current flow in the circuit. In the circuit shown in Fig. 16 there will be some small reverse current which has some slight effect on the input resistance of the transistor.

(w) The i-f frequency is determined by the difference between the frequency of the incoming signal and the frequency of the local oscillator.

(x) I-F amplifiers operate at a fixed frequency and therefore the circuit is usually somewhat simpler and can be better shielded than an rf amplifier which must be adjustable over a frequency range.

(y) To introduce a small amount of degeneration which may prevent the stage from going into oscillation.

(z) The collector is connected to a tap to prevent the comparatively low output resistance of the transistor from loading the parallel-resonant circuit made up of L_3 and C_4.

(aa) Neutralization is obtained by taking a signal from the emitter and feeding it through C_2 into L_2. L_2 inverts the signal so that the signal fed to the base will be out-of-phase with the signal fed back to the base through the collector-to-base capacity. The emitter is left unbypassed so that a signal voltage for neutralization will be developed across R_2.

(ab) The video i-f amplifier in a television receiver will have a much wider bandwidth than the sound i-f amplifier in a radio receiver. In order to get this wider bandwidth, the video i-f amplifier is operated at a much higher frequency.

(ac) A capacitor is not necessary at the high frequencies used in video i-f amplifiers. There is already enough capacity in the tube and in the circuit wiring to provide the capacity necessary to form a parallel-resonant circuit along with the primary winding of T_2.

(ad) R_3 is used to load the parallel-resonant circuit consisting of L_3 plus the transistor and distributed capacity in the circuit. The resonant circuit is loaded giving wider bandwidth.

(ae) C_3 is the neutralizing capacitor. A signal voltage is fed through it to neutralize the voltage fed through the collector–to–base capacity of the transistor.

(af) C_5 is a neutralizing capacitor. It is used to feed energy from the plate circuit back into the grid circuit to cancel out the energy fed from the plate circuit to the grid circuit through the interelectrode capacity of the tube.

(ag) The filament of the transmitting tube is quite heavy and does very little heating or cooling as the ac current goes through its cycle. Operating the filament on ac does not introduce hum into the circuit.

(ah) The tank circuit consisting of the coil and the capacitor in the plate circuit of the rf power amplifier smooth the current pulses from the tube into a pure sine wave.

(ai) The tetrode tube provides a higher power gain, and a properly designed tetrode amplifier usually does not require neutralization.

(aj) The emitter-base junction of a transistor Class C power amplifier is reverse biased.

(ak) R_1 and C_1.

(al) They are used to tune out the emitter lead inductance.

Lesson Questions

Be sure to number your Answer Sheet B203.

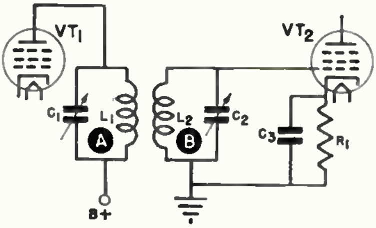
Place your Student Number on every Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time, or you may run out of lessons before new ones can reach you.

1. What type of load will be found in the plate circuit of most rf amplifiers?

2. If a 1000-KHz signal is modulated by a 3000-cycle audio signal, what will the frequencies of the sidebands be?

3. In the circuit shown to the right what type of resonant circuit is the circuit marked A; what type is the resonant circuit marked B?



4. Which type of rf amplifiers are found in radio and TV receivers, voltage amplifiers or power amplifiers?

5. Why are triode rf amplifiers frequently used in television receivers?

6. What is the purpose of C_4 in the circuit shown in Fig. 14?

7. What purpose do L_1 and C_1 in the circuit shown in Fig. 15 serve?

8. What characteristic of the junction-type field-effect transistor makes it ideally suited for use as an rf amplifier?

9. Why is the suppressor grid of a pentode tube, used as an i-f amplifier, often connected to ground rather than the cathode of the tube?

10. How is bias developed for the Class C transistor power amplifier shown in Fig. 28?

FEAR LEADS TO FAILURE

No matter how hard a person may work for success, there is nothing which can help him if he is always doubting his own ability-if he is always thinking about failure.

To be ambitious for wealth yet always expecting to be poor is like trying to get past a vicious dog when afraid of the dog and uncertain of your ability to make friends with him-in each case, fear of failure is almost certain to result in failure. Success, on the other hand, is won most often by those who believe in winning.

Never doubt for a moment that you are going to succeed. Look forward to that success with just as much assurance as you look forward to the dawn of another day, then work-with all that's in you-for success.

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ACHIEVEMENT THROUGH ELECTRONICS

WIDE-BAND AMPLIFIERS

B204

NATIONAL RADIO INSTITUTE • WASHINGTON, D. C.

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STUDY SCHEDULE

☐ 1. Introduction . . . . **Pages 1 - 2**
A look at what you will study in this lesson.

☐ 2. Logarithms and Decibels . . . . **Pages 3 - 10**
You are introduced to the theory of logarithms, you learn what we mean by a decibel and learn how the decibel is used.

☐ 3. Extending the High-Frequency Response of an Amplifier . . . . **Pages 11 - 24**
You learn what factors limit the high-frequency of an amplifier and what can be done to improve it.

☐ 4. Extending the Low-Frequency Response of an Amplifier . . . . **Pages 24 - 31**
You study the factors affecting the low-frequency response and how they can be compensated for.

☐ 5. Typical Wide-Band Amplifiers . . . . **Pages 32 - 41**
Both typical tube and transistor wide-band amplifiers are discussed.

☐ 6. Answer the Lesson Questions.

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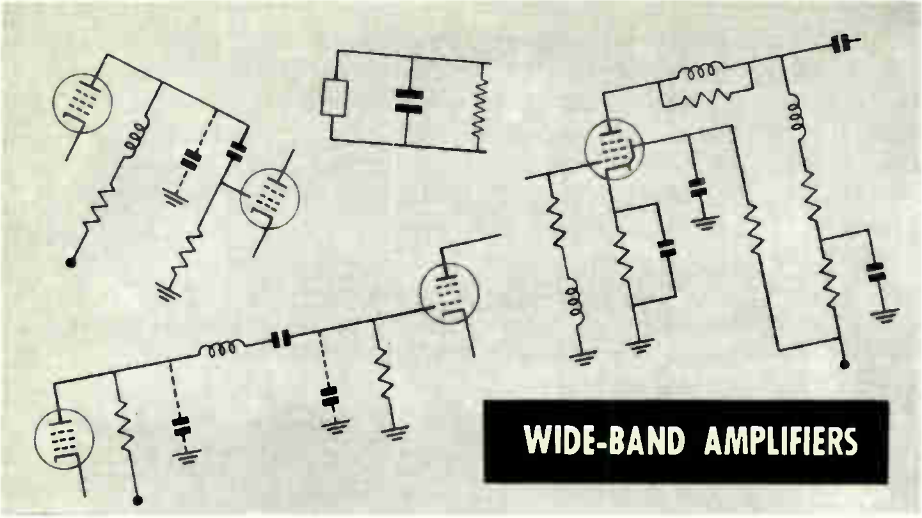


WIDE-BAND AMPLIFIERS

A wide-band amplifier is an amplifier designed to amplify a wide range of signal frequencies. The amplifiers you studied in earlier lessons were designed to amplify only a limited range of frequencies. For example, a low-frequency voltage amplifier such as found in a typical radio receiver or in the sound portion of a television receiver, is designed to amplify only frequencies from about 100 Hertz up to about 10,000 Hertz. Even in a high fidelity amplifier or a high fidelity radio receiver, the low-frequency voltage amplifier is designed to amplify only frequencies from about 10 Hertz up to about 30,000 Hertz. Amplifiers of this type are entirely unsatisfactory for use as video amplifiers in a television receiver. Here, we need a special wide-band amplifier that can amplify all the signals in a TV picture from only a few cycles per second (a few Hertz) all the way up to several megacycles per second (several megahertz). Furthermore, the amplifier must be able to amplify all these signals equally well and must not shift the phase of any signal more than or less than the phase of the other signals.

In your earlier lesson on low-frequency amplifiers you learned that the response of a resistance-capacitance coupled amplifier is limited by three things. The low-frequency response is limited by the reactance of the coupling capacitor. In amplifiers that use vacuum tubes, when the coupling capacitor has a reactance that is equal to or greater than the resistance of the grid resistor in the following stage, the gain of the amplifier begins to drop to such a low level that considerable frequency distortion results. You will remember that we have frequency distortion in an amplifier when signals of different frequencies do not receive the same amount of amplification. In transistor amplifiers we have the same problem when the reactance of the coupling capacitor becomes equal to or greater than the input resistance of the following stage. This input resistance is equal to the input resistance of the transistor itself (which is usually quite low) in parallel with any resistance connected between the base and the emitter.

The high-frequency response is limited by the shunt capacities in the circuit. At high frequencies the shunt capacities in the circuit have a low enough reactance to have an appreciable effect on the gain of the amplifier. In a vacuum tube amplifier, the shunt capacities reduce the effective value of the plate load resistance. In a transistor amplifier they reduce the effective collector load resistance. In both cases the gain of the amplifier drops so that it no longer gives satisfactory results.

Both the low-frequency and the high-frequency response are limited by phase shift. You will remember that the current flowing through a capacitor leads the voltage across it by 90 degrees. Thus, as the capacitive reactance in the circuit becomes appreciable, there is an appreciable phase shift. This means that both low-frequency and high-frequency signals are shifted in phase with reference to middle-frequency signals. In TV receivers and in other electronic devices, this phase shift can appreciably affect the performance of the equipment.

In this lesson we are going to learn what steps are taken to improve both the low-frequency response and the high-frequency response of resistance-coupled amplifiers so that they can be used as wide-band amplifiers.

Another thing we are going to investigate in this lesson is the method used to describe the performance of an amplifier. For example, a manufacturer may say that an amplifier is flat from 100 Hertz to 100 KHz. This means that the gain of the amplifier is constant from 100 Hertz to 100 KHz. In other words, if the voltage gain is 100 at 100 Hertz it will be 100 at all frequencies between 100 Hertz and 100 KHz.

An amplifier that is flat from 100 Hertz to 100 KHz is quite a good amplifier. Usually it is impossible to design an amplifier that has exactly the same gain over a wide range of frequencies. The gain may be a little higher or a little lower at some frequencies than it is at others. The exact variation in gain that can be tolerated depends largely on what the amplifier is to be used for. Therefore, manufacturers must have a method of describing how much the gain of the amplifier varies. To do this they use a unit called the decibel (db). Since the decibel is such a useful unit and since you will encounter it in all branches of electronics, we will learn something about it now before going ahead with our study of wide-band amplifiers. We will then be able to use the decibel in describing amplifier performance so you can see how it is used by manufacturers, engineers, and technicians.

Logarithms and Decibels

The decibel is a logarithmic ratio. In other words, it is a ratio that is based on logarithms. Therefore, before we can understand what a decibel is, we must first learn something about logarithms.

There are two important types of logarithms in use today. One is called a "common" logarithm and the other a "natural" logarithm. Common logarithms are based on the number 10. This is the type of logarithm that we will study and use now.

THE THEORY OF LOGARITHMS

The basic idea of logarithms comes from the fact that any number can be expressed as the "power" of another number. The "power" of a number is the product of a number multiplied by itself a given number of times. The first power of a number is the number itself; the second power is that number multiplied by itself; the third power is that number multiplied by itself twice, etc.

This is easiest to understand by taking an example. In the system of common logarithms, we express all numbers as powers of 10; so we will use 10 as our example. The number 10 itself is equal to 10 to the first power. This can be written 10^1. 100 is equal to 10 X 10. This is 10 to the second power, and can be written 10^2. Similarly, 1000 is equal to 10 X 10 X 10, which is 10 to the third power, and can be written 10^3. The number 10,000 is 10 to the fourth power. Since 10 X 10 X 10 X 10 is equal to 10,000 it can be written 10^4.

Now, as we have said, 100 is 10 to the second power; the logarithm of 100 is simply the power to which 10 must be raised to give us 100. Ten must be raised to the second power (10^2) to give us 100. Therefore, the logarithm of 100 is 2. Similarly the logarithm of 1000 is 3, and the logarithm of 10,000 is 4. The logarithm of 10 is 1.

This is not very complicated when a number is an exact power of 10. But let us consider the numbers between 10 and 100. It is a little more difficult to see how a number between 10 and 100 can be expressed as a power of 10. Actually, this is quite difficult to work out mathematically, but it can be done. Fortunately all these values have been worked out and are available in tables called logarithm or "log" tables. If you want to know the logarithm of a number, you must refer to the table. For example, the logarithm of the number 2 is .301. This means that if it were possible to multiply the number 10 by itself .301 times, the product would be 2. This can be written $10^{.301}$. The exponent, or power, .301, is called the logarithm.

Now let's take the number 20. The logarithm of 20 is 1.301. Notice now that the logarithm is divided into two parts - one part to the left of the decimal point, the other to the right of the decimal point. The part to the left is called the "characteristic" and the part to the right is called the "mantissa".

In the logarithm of a number, the "characteristic," is 1 less than the number of figures to the left of the decimal point in the original number. In other words, any number between 10 and 99 would have a logarithm with a characteristic of 1. The important rule to remember here is that the characteristic is always one number smaller than there are whole numbers in the original number. Thus if the logarithm of a number is exactly three, the number itself is exactly 1000 because 1000 has four places to the left of the decimal.

The chart shown in Fig. 1 gives the characteristics of the numbers you are likely to encounter.

For numbers from:			Characteristic
1	to	9	0.
10	to	99	1. (10^1)
100	to	999	2. (10^2)
1,000	to	9,999	3. (10^3)
10,000	to	99,999	4. (10^4)
100,000	to	999,999	5. (10^5)

Fig. 1. The characteristics of numbers from 1 to 999,999.

A table of logarithms is shown on pages 6 and 7. As you can see, it shows only the mantissas. When you are looking up a logarithm, you must supply the characteristic from the information in Fig. 1. Notice that the table does not list an infinite number of mantissas because logarithms repeat themselves. For example, the mantissa of a logarithm will be the same for the number 2 as it is for the number 20, or 200 or 2000. The only difference in the logarithm will be in the characteristic. For example, the logarithm of the number 2 is .301. The logarithm of 20 is 1.301 and the logarithm of 200 is 2.301. The logarithm table would simply give you a value for the number 2. If the number is 20 or 200 or 2000, you must remember to add the correct characteristic in front of the mantissa. Similarly the mantissa of the logarithm of 21 would be the same as the mantissa of the logarithm of 210, the difference would be in the characteristic. The log of 21 is 1.322 and the log of 210 is 2.322.

Let's take the number 39 and see how we would find the logarithm. We know that the characteristic will be 1, because it is always equal to 1 less than the number of figures in the antilog. (The original number is called the antilog.)

Now, to find the mantissa, refer to the log tables. First find the number (39) in the N column. Since the number 39 is the complete number, follow across to the 0 column. There you will find 5911, which is the mantissa. Since you already know that the characteristic is 1, you have the complete logarithm of 39, that is, 1.5911.

If the number for which you wanted the logarithm had 3 places, you would find the first two in the N column, then follow across to the column under the third digit. For example, to find the logarithm of 399, you would find 39 in the N column, and then follow across to the 9 column, where you would find 6010 for the mantissa. Since the number 399 has 3 places, you know the characteristic is 2, so the complete logarithm is 2.6010.

The last column in the log table is labeled P.P.; this is the "Proportional Parts" column. This column is used when the number has more than three digits. For example, the log of 399 is 2.6010. The log of 3990 has the same mantissa, .6010, but the characteristic is 3, so the log is 3.6010. But what about the log of the number 3995? It is greater than the log of 3990, but less than the log of 4000. The proportional parts column is used to get the log of 3995. We look in this column under the heading 5 and get 6. So to the log of 3990, which is 3.6010 we add .0006 and get 3.6016, which is the log of 3995. The proportional parts column only goes up to 5, so if the fourth digit is greater than 5, we add the proportional parts of two numbers that add up to the fourth digit. For example, to express 3998, we take the log of 3990, which is 3.6010 and add the proportional parts under 3 and 5 (3 and 6) and get 3.6019, which is the log of 3998. We could also take the log of 4000, which is 3.6021 and subtract the value under the 2 column and get 3.6019.

THE DECIBEL

Many years ago engineers working on telephone installations introduced a unit of power measurement called the bel. This unit of measurement was named for Alexander Graham Bell, the inventor of the telephone.

The bel was introduced as a unit of measurement because engineers and scientists discovered that the human ear responds to variations in loudness in an approximately logarithmic manner. Therefore, it is convenient to have a unit that can be used to express the ratio between the power of two signals in a logarithmic manner. The bel is simply the logarithm of the ratio of the power of two signals. For example, if we had a signal power of 100 watts and another signal power of 10 watts, and we wished to express the ratio of these two signals in bels, we would use the formula:

$$\text{bels} = \log \frac{P_1}{P_2}$$

and substitute 100 watts for P_1 and 10 watts for P_2, and we would get:

$$\text{bels} = \log \frac{100}{10}$$

$$\text{bels} = \log 10$$

Now the log of 10 is 1, so this power ratio is equal to 1 bel. In other words, a power ratio of 100 watts to 10 watts, which is a ratio of 10 to 1, is equivalent to 1 bel. Thus a power ratio of 10 watts to 1 watt or 1000 watts to 100 watts are both power ratios of 10 to 1 so they also represent a change in power of 1 bel.

The bel proved to be too large a unit to handle easily, so another unit, one-tenth the size of the bel was introduced. This unit is called the decibel (abbreviated db). Thus the commonly used measuring unit is the decibel; the prefix deci means one-tenth. A power ratio in decibels is defined as:

$$\text{db} = 10 \log \frac{P_1}{P_2}$$

which simply means that the ratio of two powers expressed in decibels is equal to ten times the logarithm of the ratio of the two powers.

You will notice that the above relationship refers to power ratios only. It is common in electronics work to refer to voltage ratios, especially when calculating or discussing the gain of amplifiers. When the ratio between two voltages is calculated in decibels, we must modify the decibel equation to take care of the fact that the power ratios are proportional to the squares of voltage ratios since $P = E^2 \div R$. The formula to express voltage ratios in decibels is:

$$\text{db} = 20 \log \frac{E_1}{E_2}$$

It is important to keep in mind that the voltage formula can be used only when the resistances in the two circuits being compared are equal. If we are trying to compare voltages developed across resis-

N	0	1	2	3	4	5	6	7	8	9	P. P. 1·2·3·4·5
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4·8·12·17·21
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4·8·11·15·19
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3·7·10·14·17
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3·6·10·13·16
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3·6·9·12·15
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3·6·8·11·14
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3·5·8·11·13
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2·5·7·10·12
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2·5·7·9·12
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2·4·7·9·11
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2·4·5·8·11
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2·4·6·8·10
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2·4·6·8·10
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2·4·5·7·9
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2·4·5·7·9
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2·3·5·7·9
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2·3·5·7·8
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2·3·5·6·8
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2·3·5·6·8
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1·3·4·6·7
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1·3·4·6·7
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1·3·4·6·7
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1·3·4·5·7
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1·3·4·5·6
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1·3·4·5·6
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1·2·4·5·6
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1·2·4·5·6
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1·2·3·5·6
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1·2·3·5·6
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1·2·3·4·6
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1·2·3·4·5
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1·2·3·4·5
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1·2·3·4·5
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1·2·3·4·5
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1·2·3·4·5
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1·2·3·4·5
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1·2·3·4·5
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1·2·3·4·5
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1·2·3·4·4
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1·2·3·4·4
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1·2·3·3·4
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1·2·3·3·4
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1·2·2·3·4
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1·2·2·3·4
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1·2·2·3·4

N	0	1	2	3	4	5	6	7	8	9	P.P.				
											1	2	3	4	5
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	3	3
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2

tors of unequal value, we must convert the voltage to the power developed across the resistors and then use the power formula.

USING THE DECIBEL

It so happens that the smallest amount of change in sound power level that can be distinguished by the average human ear is 1 decibel on a sine wave signal, or 3 db on complex waves such as the average human voice.

Because the decibel is such a convenient unit for expressing changes in sound level, manufacturers of audio equipment have for some time used it in describing the response of their amplifiers. This practice has generally spread into describing the performance of wideband amplifiers.

Let us now see two examples of how the decibel can be used to describe an amplifier response. In an earlier lesson we discussed the so-called half-power points and the .707 voltage points in an amplifier. Remember that when the reactance of the coupling capacitor used between two resistance-capacitance stages becomes equal to the resistance in the input of the following stage, the voltage gain of the amplifier drops to .707 (70.7%) of what it is at medium frequencies. At the same time, since the voltage drops to .707, the current also drops to .707. The power, which is the product of E X I, is therefore .707 X .707, which is approximately .5 times what it is at the middle frequencies.

Thus we called this point the half-power point. Now let's use decibels to see how much of a change this represents.

Considering first the change in output voltage, let's call E_1, the voltage at the middle frequencies, 1; E_2, the voltage at the low frequency, will then be .707. Thus the change in db is:

$$\text{db} = 20 \log \frac{E_1}{E_2}$$

and substituting 1 for E_1 and .707 for E_2 we get:

$$\text{db} = 20 \log \frac{1}{.707}$$

Now when we divide .707 into 1 we get the following:

$$.707\overline{)\ 1\ }$$

We get rid of the decimal in the division by moving the decimal point in each number three places to the right so we have 1000 ÷ 707, which is:

$$\begin{array}{r}
1.414 \\
707\overline{)1000.} \\
\underline{707} \\
2930 \\
\underline{2828} \\
1020 \\
\underline{707} \\
3130 \\
\underline{2828} \\
302
\end{array}$$

Thus we can see that 1 divided by .707 is equal to 1.414, plus a remainder. For our purposes 1.41 is close enough. Thus we have:

$$\text{db} = 20 \log 1.41$$

The log of 1.41 is .1492, which we can call .15, so we have:

$$db = 20 \times .15 = 3$$

Hence the change in db is 3 db. This means that the voltage gain of the amplifier has changed by 3 db. In this case, at the frequency when the reactance of the coupling capacitor is equal to the resistance in the input circuit of the following stage, the voltage output will have dropped 3 db from what it is at the middle-frequency range.

Now let's see what results we get if we use the power formula. Remember that when the voltage drops to .707, the current also drops to .707, and therefore the power drops to .5. Thus, using the formula:

$$db = 10 \log \frac{P_1}{P_2}$$

and substituting 1 for P_1 and .5 for P_2 we get:

$$db = 10 \log \frac{1}{.5}$$

and since 1 ÷ .5 = 2, we have:

$$db = 10 \log 2$$

The log of 2 is .301, and 10 times this is 3.01, or for all practical purposes, 3 db. Thus, whether we use the power formula or the voltage formula we get the same change in db.

Manufacturers frequently use decibels to express the change in power output over a given frequency range in a power amplifier or the change in voltage output in a voltage amplifier. For example, in describing a voltage amplifier, the manufacturer might say that the voltage gain of the amplifier is flat within 3 db from 10 Hertz to 3 megahertz. This means that the voltage gain of the amplifier does not vary by more than 3 db above or below the middle-frequency gain of the amplifier between the frequencies of 10 Hertz and 3 MHz. You know that 3 db represents a voltage change of .707, or in other words, the gain of the amplifier will not vary more than 29.3% (100% - 70.7%) from what it is at the middle frequencies. The gain will be at least 70.7% of the middle-frequency gain within the frequency range of from 10 Hz to 3 MHz.

The manufacturer of a certain power amplifier might claim that the power output from the amplifier is flat within a certain number of db from 50 Hertz to 1000 Hertz. This means that the power output between these frequency limits is within the specified number of db of the specified power output.

One of the advantages of using the decibel in comparing power ratios is that it gives a pretty good picture of how the amplifier will sound. For example, if you have a 5-watt amplifier that is capable of putting out 5 watts of audio power in the middle-frequency range, but only 1 watt at a frequency of 100 Hertz, you would have a power ratio of 5 to 1. This represents a change of 7 db, which would be very noticeable, even though the actual difference in power output is only 4 watts. On the other hand, if you had an amplifier capable of putting out 100 watts of audio power at the middle frequencies, and dropped to 50 watts at 100 Hz, although the change in power is actually 50 watts, the power ratio is 2 and the db change only 3 db. This is a smaller change in db than the change from 5 watts to 1 watt. This is as it should be, because you would notice a greater change in going from 5 watts to 1

Voltage Ratio	DB	Power Ratio	DB
1	0	1	0
2	6.0	2	3.0
3	9.6	3	4.8
4	12.0	4	6.0
5	14.0	5	7.0
6	15.6	6	7.8
7	16.8	7	8.4
8	18.0	8	9.0
9	19.2	9	9.6
10	20.0	10	10.0
20	26.0	20	13.0
30	29.6	30	14.8
40	32.0	40	16.0
50	34.0	50	17.0
60	35.6	60	17.8
70	36.8	70	18.4
80	38.0	80	19.0
90	39.0	90	19.6
100	40.0	100	20.0
1,000	60.0	1,000	30.0
10,000	80.0	10,000	40.0

Fig. 2. Decibel values corresponding to voltage and power ratios.

watt than you would in going from 100 watts to 50 watts.

The chart shown in Fig. 2 is a table of decibel values corresponding to voltage and power gains. This would give you an idea of what the voltage ratio or the power ratio is for certain db values.

The decibel is an important unit in the electronic field. You should be familiar with what it is and how it is used. If you plan on doing radio and TV service work you do not have to be able to calculate either voltage gain or power ratios in decibels. However, you should realize what the decibel is, and become familiar with its use. As a technician you will run into it time and time again. Manufacturers frequently use it in describing the performance of electronic equipment. You'll be called on to interpret the meaning of characteristics of this type. Also an understanding of what a decibel is and how it is used will help you in evaluating the performance of certain types of electronic equipment. By comparing an amplifier with the manufacturer's specifications, you can decide whether or not the amplifier is performing as well as it is supposed to be able to.

If you intend to go into communications or into industry as an electronics technician you should be able to calculate both voltage gain and power ratios in decibels. The Self-Test Questions that follow will give you an opportunity to try to perform these calculations; you can check your answers with those given.

SELF-TEST QUESTIONS

(a) What is a common logarithm?

(b) What is the part of the logarithm to the left of the decimal point called?

(c) What is the part of the logarithm to the right of the decimal point called?

(d) What is the characteristic of numbers from 100 to 999?

(e) Write the logarithm of 7.

(f) Write the logarithm of 700.

(g) Write the logarithm of 41.7.

(h) What is the bel?

(i) What is the decibel?

(j) If the power output of an amplifier changes from 222 watts to 37 watts, how many db does this change represent?

(k) If a defect develops in an amplifier and the output voltage drops from 150 volts to 75 volts, what change in decibels does this represent?

Extending the High-Frequency Response of an Amplifier

A schematic diagram of a typical two-stage R-C coupled amplifier using vacuum tubes is shown in Fig. 3. The first stage, V_1, uses a triode tube, and the second stage, V_2, uses a pentode tube. In your study of low-frequency amplifiers, you learned that the high-frequency response of an R-C coupled amplifier is limited by shunt capacities in the circuit. You will remember that the first tube, V_1, has a certain capacity between the plate and cathode of the tube. This capacity in effect is in parallel with the plate load resistor R_3. You will remember that as far as the signal is concerned, R_3 is connected between the plate of the tube and ground. The end of R_3 that connects to the positive side of the power supply is at signal ground potential because the output filter capacitor in the power supply will be so large that at signal frequencies it acts like a short circuit. The cathode of the tube is adequately bypassed by the bypass capacitor C_1 so that the plate-to-cathode capacity of V_1 is in effect connected directly between the plate of the tube and ground, or in parallel with R_3.

There is also another capacity that must be considered in the input circuit of V_2. This capacity is the grid-to-cathode capacity of the tube. This capacity will depend upon the tube structure and also upon the gain of the stage. At high frequencies, the coupling capacitor C_2 has such a low reactance that it can be ignored so that in effect the output capacity of V_1 is connected directly in parallel with the input capacity of V_2.

In addition to the capacities in the tubes V_1 and V_2, there will be a certain amount of stray capacity in the wiring. For example, the coupling capacitor C_2 will have a certain capacity to ground, the lead connecting C_2 to V_1 and V_2 will also have a certain capacity to ground. All this capacity is added to the capacity in the output circuit of V_1 and the capacity

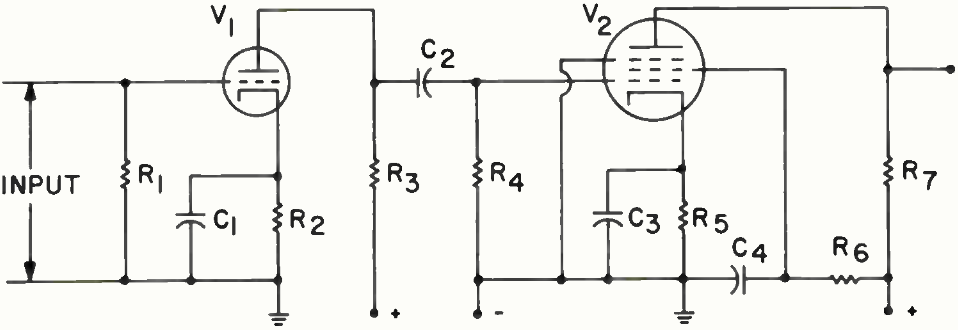


Fig. 3. An R-C coupled amplifier.

in the input circuit of V_2, and tends to limit the high-frequency response of the amplifier.

EFFECT OF SHUNT CAPACITY

In Fig. 4 we have shown the equivalent circuits of the coupling network used between V_1 and V_2 at middle frequencies and at high frequencies. The circuit in A is the equivalent circuit of the coupling network at middle frequencies. The resistor $R_{3\text{-}4}$ represents the resistance of R_3 and R_4 in parallel. As far as the signal is concerned, they are in parallel because the reactance of C_2 is so low that the capacitor acts like a short circuit. The parallel combination of R_3 and R_4 will be almost equal to the resistance of R_3 because R_4, which is the grid resistor of V_2, is many times larger than the plate resistor R_3. Therefore as far as the load in the plate circuit of V_1 is concerned, it is almost entirely controlled by the value of R_3. R_3 will usually have a resistance somewhere between 10,000 and 100,000 ohms. R_4, on the other hand, will be considerably larger than this, usually between .25 and a .5 megohm. The value of R_4 is limited by the type of tube used for V_2. Some tubes will develop a negative bias due to electrons accidentally striking the grid if too large a resistance is used in the grid circuit. Other tubes may have a small amount of gas present inside of the tube; these tubes will develop a positive voltage on the grid if too large a grid resistor is used. However, in any case, even though R_4 is in parallel with R_3 at middle audio frequencies, it has very little effect insofar as reducing the plate load is concerned because its resistance is usually considerably greater than that of R_3.

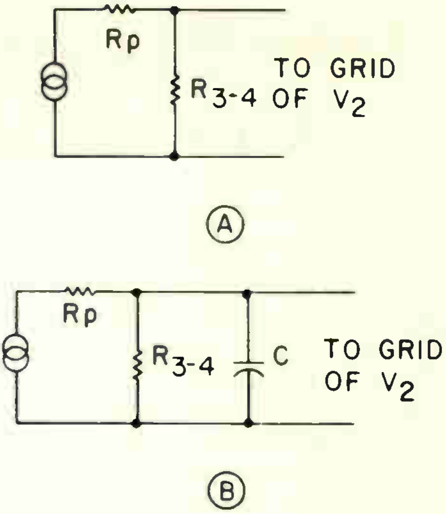


Fig. 4. Equivalent circuits of coupling networks between V_1 and V_2. "A" shows the equivalent circuit at middle frequencies and "B" the equivalent circuit at high frequencies.

In Fig. 4B we have shown the equivalent circuit of the coupling network at high frequencies. The capacity C is used to represent the sum of the output capacity of V_1, the input capacity of V_2, and the distributed capacities in the circuit. Notice that C is connected directly across $R_{3\text{-}4}$.

As the frequency of the signal amplified by the amplifier increases, the capacitive reactance of C decreases. You will remember that the capacitive reactance of the capacitor is given by the formula:

$$X_C = \frac{1}{6.28 \times f \times C}$$

From the formula you can see that if either f or C increases, the value of the capacitive reactance will decrease.

At some frequency the capacitive reactance of C will be equal to the resistance of the parallel combination of $R_{3\text{-}4}$. You will remember that we pointed out previously that when this happens the signal reaching the grid of V_2 will actually be 70.7% of the signal reaching the grid of V_2 at middle audio frequencies. You will remember we called this the half-power point; this is the point at which the signal reaching the grid of V_2 is 3 db lower than the signal reaching the grid of V_2 at middle audio frequencies. Now let us see the steps we can take to increase the frequency at which the signal reaching the grid of V_2 drops 3 db.

REDUCING THE SHUNTING EFFECT

In a practical amplifier that is to be designed to amplify signals of widely different frequencies, we try to keep the response of the amplifier as flat as possible over the required frequency range. This means that we try to design the amplifier so that it will give all the signal frequencies it must amplify the same amount of amplification. If all the signal frequencies receive the same amount of amplification, we say that the amplifier is flat over the range of frequencies it must amplify. However, in actual practice it is impossible to get an amplifier that is exactly flat over a very wide frequency range, so we generally have to be satisfied with an amplifier whose gain is flat within a few db over the frequency range for which the amplifier is designed.

To give a practical example of how the high-frequency response of an amplifier can be extended, let us see what we can do to extend the frequency response of an amplifier like the one shown in Fig. 3. Suppose that we want to be able to amplify signals up to 200 KHz so that the gain of the amplifier at 200 KHz is within 3 db of the gain at the middle frequency. If in checking the amplifier we find that the gain drops 3 db at 100 KHz, we can extend the frequency response of the amplifier by reducing the size of the plate load resistor R_3.

If the gain drops 3 db at 100 KHz, this means that the capacitive reactance of the shunt capacity across the parallel combination of R_3 and R_4 must be equal to the value of the parallel resistors at a frequency of 100 KHz. You will remember that R_4 is much larger than R_3. Therefore, the value of the combination will be almost equal to the value of R_3 alone. If we cut the value of R_3 in half, we will in effect be cutting the value of R_3 and R_4 in parallel, in half. Then the reactance of the capacitance will be equal to $R_{3\text{-}4}$ at twice the original frequency of 100 KHz. Therefore by simply reducing the plate resistor R_3 in the plate circuit of V_1, we can extend the gain of the amplifier at high frequencies. Of course, what we are actually doing is reducing the gain of the amplifier at the low and middle frequencies in order to flatten the response of the amplifier over a wider frequency range. In spite of the fact that this might seem to be somewhat of a disadvantage, it is the method most widely used to extend the high-frequency response of an amplifier. If in reducing the amplifier gain by reducing the plate load resistance, we find that we do not have sufficient gain in the amplifier, then we can overcome this difficulty simply by adding an additional stage.

In video amplifiers found in television receivers, where the frequency response must be reasonably flat up to a frequency of several megahertz, the plate load resistor R_3 may have a resistance of only a few thousand ohms. This makes it possible to obtain a reasonably flat gain over a wide frequency range. Suppose for example, that the value of R_3 is 94,000 ohms and that the gain of the amplifier drops 3 db at 100 KHz. By reducing the size of R_3 to 47,000 ohms, we can extend the 3 db down point to 200 KHz. If we reduce the value of R_3 to 4,700 ohms, then we can extend the 3 db down point to 2 MHz. Of course, the gain of the amplifier will be much lower at low and middle frequencies with a 4700-ohm resistor in the plate circuit of V_1 than it will be with a 47,000-ohm or a 94,000-ohm resistor in the plate circuit. But the gain will be essentially flat from a very low frequency up to approximately 2 MHz with the 4.7K resistor in the plate circuit. Where a flat response over a wide frequency range is required, reducing the size of the plate load resistor in order to reduce the shunting effect of the shunt capacity is the simplest way of obtaining the wide frequency response. When we use a very small value of plate load resistor, it is so small compared to the resistance of the grid resistor in the following stage, that we can forget the shunting effect of the grid resistor and consider the plate load as equal to the value of the plate load resistor. In the next section dealing with high-frequency compensation we will do this.

In the example we have given, we found that by reducing the size of R_3 to 4700 ohms we can extend the 3 db down point to 2 MHz. However, in some applications we may want to keep the gain essentially flat out to 2 MHz or higher. We cannot reduce the value of R_3 much below 4700 ohms or we'll get very little gain from V_1. Therefore, we have to use another method of extending the high-frequency response of the amplifier. We can do this by high-frequency compensation.

HIGH-FREQUENCY COMPENSATION

A method widely used to improve the response of an amplifier at high frequencies is called compensation. By compensation we mean that we add something to the circuit to compensate for other undesirable effects. As you might guess, since the capacity and capacitive reactance are the causes of difficulty at high frequencies, to counteract this, we add inductance that will introduce inductive reactance into the circuit.

The coils that are added to the circuit to improve the high-frequency response are called peaking coils. They are so-called because they will peak the response at some frequency above the maximum frequency that could be amplified by the amplifier without these coils. There are actually three types of circuits that can be used. There is a circuit known as shunt peaking, one known as series peaking and

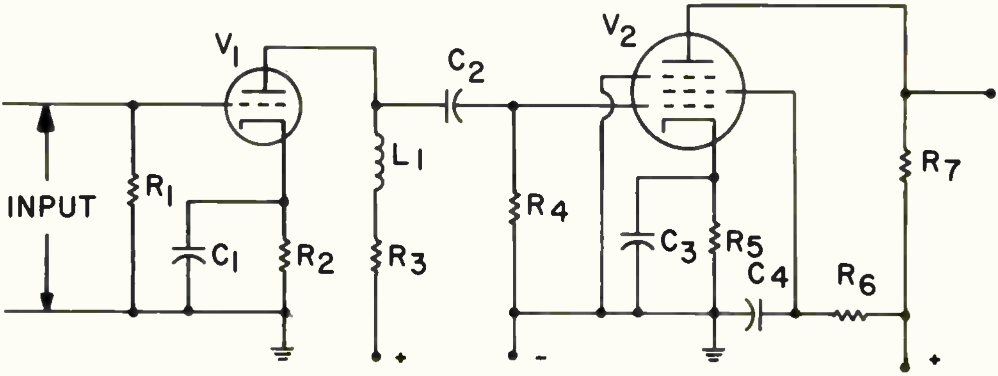


Fig. 5. A wide-band amplifier with shunt-peaking coil.

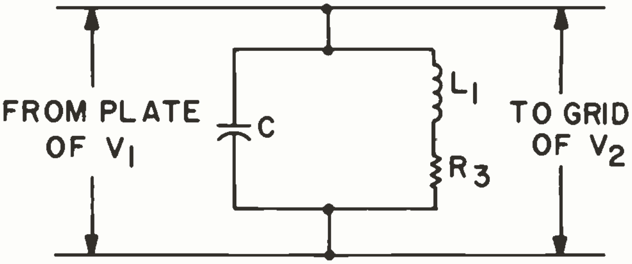


Fig. 6. Equivalent circuit of coupling network between V_1 and V_2.

one that is a combination of shunt and series peaking. The combination of shunt and series peaking is most widely used, but because shunt peaking and series peaking alone are somewhat simpler to understand than the combination, we will look at these two types of peaking-circuits first.

Shunt Peaking. Fig. 5 is a schematic diagram showing how shunt peaking can be added to the R-C coupled amplifier circuit shown in Fig. 3. Notice that the two circuits are identical except that L_1 has been added in series with R_3 in the plate circuit of V_1. The equivalent circuit of the coupling network between V_1 and V_2 with this peaking coil added is shown in Fig. 6.

Notice that in Fig. 6 we see that the peaking coil and load resistor are in parallel with the capacity C which represents the output capacity of V_1, the input capacity of V_2, and the distributed capacity in the circuit. The idea in back of the peaking coil is to select a value of inductance so that a parallel-resonant circuit is formed at a frequency above the frequency at which the gain would drop 3 db without the peaking coil in the circuit. Then, as the frequency of the signal to be amplified approaches the 3 db down point, without the peaking coil, the parallel-resonant circuit begins to take over. You will remember that one of the characteristics of the parallel-resonant circuit is that it acts like a high resistance at resonance. Therefore instead of the load impedance of V_1 dropping because of the shunting effect of the capacity, the load impedance actually begins to increase because of the high resistance of the parallel-resonant circuit. This will cause the gain of the amplifier to increase slightly so that higher frequency signals can be amplified with the same gain as signals at middle frequencies.

At first you might think that the resistance R_3 that is in series with the peaking coil, would lower the Q of the parallel-resonant circuit so that the circuit would not be particularly affected. The resistance does in fact lower the Q of the resonant circuit, but this is desirable. The purpose of L_1 is to keep the gain of the amplifier flat at higher frequencies. R_3 reduces the resistance of the parallel-resonant circuit and tends to keep the load in the plate circuit of V_1 more or less constant. If R_3 does not lower the Q of the resonant circuit sufficiently, then we have a situation where the gain rises as the combination of L_1 and C approach resonance. We'll actually have a peak in the response at resonance, if the coil is not loaded sufficiently, so that the gain in the circuit is much higher at this fre-

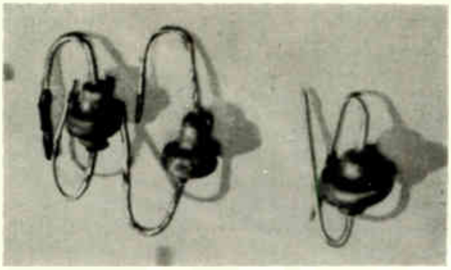


Fig. 7. Peaking coils are wound on ½ watt resistors.

quency than it is at lower frequencies. This is called over compensation, and in most cases it is undesirable. A small amount of over compensation, however, is sometimes used in order to produce some desirable effects. For example, a small amount of over compensation in the video amplifier of a television receiver may tend to make the fine detail in the picture somewhat sharper. However, extensive over compensation will cause ringing where oscillation will occur in the resonant circuit. In a television picture, this would result in fine details being repeated. In other words, if there was a vertical pole appearing in a certain scene, a second or third pole might appear in the picture displaced slightly to the right of the original pole.

Peaking coils are often wound on 1/2 watt resistors If there is not sufficient loading of the resonant circuit to prevent ringing or over peaking, a comparatively low-resistance resistor is used. This provides additional loading on a resonant circuit. Where the circuit already has sufficient loading, the coil can be wound on a dummy form which looks like a 1/2 watt resistor but actually has no electrical connection through it. In some cases, rather than go to the trouble of getting dummy forms on which to wind a coil of this type, manufacturers will simply wind the coil on a very high value resistance. The resistance of the resistor is so high that it has no appreciable loading effect on the circuit. A number of typical peaking coils are shown in Fig. 7.

Series Peaking. Two circuits using series peaking are shown in Fig. 8. The series-peaking coil is labeled L_1 in both circuits. Although L_1 is placed in a slightly different position in the two circuits, the net electrical effect is the same. Coil L_1 isolates the output capacity of V_1 from the input capacity of V_2. At the same time, the value of L_1 is selected so that it will resonate with the input capacity of V_2 at a frequency near or slightly above the frequency at which the gain of the amplifier would drop to 70.7% of the mid-frequency gain without compensation.

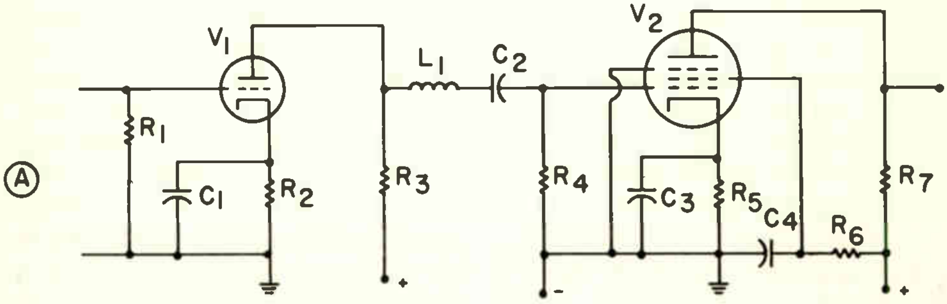


Fig. 8A. Series-peaked wide-band amplifier.

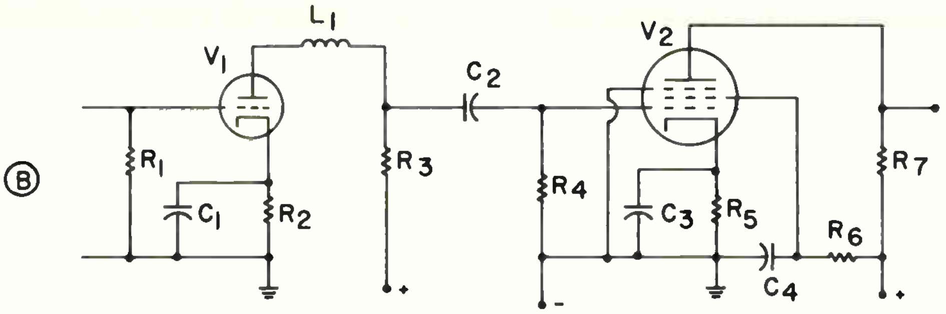
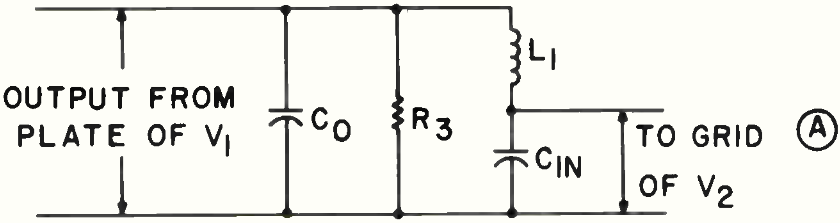


Fig. 8B. Series-peaked wide-band amplifier similar to that shown in Fig. 8A.

In Fig. 9 we have shown the equivalent circuit of the coupling network. Fig. 9A shows the equivalent of the circuit shown in Fig. 8A. Notice that here we have the capacitor labeled C_O. This represents the output capacity of V_1. This capacity is in parallel with the plate load resistor R_3. Since the output capacity of V_1 represents only a fraction of the total capacity made up of the output capacity, plus the input capacity of V_2, plus the wiring capacity in the amplifier, the gain of the amplifier will not fall off so rapidly. In other words, we have effectively reduced the capacity that is shunting R_3. At the same time, by connecting L_1 into the



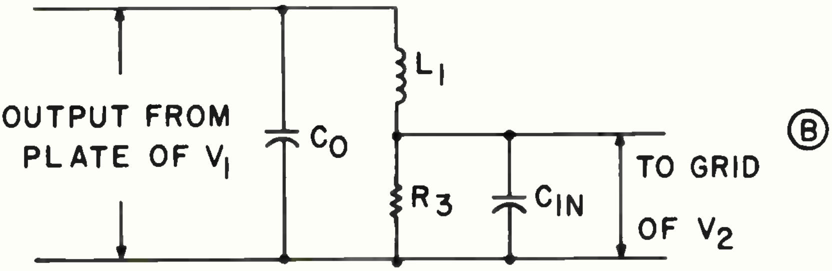


Fig. 9. Equivalent circuits of coupling network in Fig. 8.

circuit (selecting it so that we will resonate it with the input capacity of V_2), we have formed a series-resonant circuit consisting of L_1 and the input capacity of V_2. You know that in a series-resonant circuit there will be a resonant voltage step-up at the resonant frequency. Therefore we will have a resonant voltage step-up across C_{in} at the resonant frequency. This means that although there may be some tendency for the voltage across R_3 to drop at this frequency (because of the shunting effect of the output capacity of V_1), the resonant circuit is able to more than compensate for this drop-off in output from V_1, so that the input voltage of V_2 may actually be higher at high frequencies than the input voltage to V_2 at middle frequencies.

It is usually possible to obtain better peaking with a series-peaking coil than with a shunt-peaking coil. The input capacity of V_2 is usually much larger than the output capacity of V_1, so that splitting the two capacities by means of the peaking coil results in increased output from V_1. At the same time, by using the coil with a high Q, a high resonant voltage step-up can be obtained so that the input signal to V_2 will be substantially boosted. The resistor R_3, which is across the resonant circuit, loads the circuit to prevent over compensation. In some circuits the peaking coil may be loaded by winding it on a resistor to reduce the Q of the circuit still further when the value of the plate load resistor is too high to prevent excessive over compensation. As you will remember, over compensation results in excessive increase in amplification at the high frequency to which the circuit is peaked, and in most cases this is to be avoided.

In Fig. 9B we have shown the equivalent circuit for the circuit shown in Fig. 8B. Here the circuit is somewhat different from the circuit shown at A. In this circuit the load resistor R_3 is across C_{in} at the high frequencies instead of across the entire series circuit. Again at high frequencies the peaking coil L_1 forms a series resonant circuit with the input capacity in the grid circuit of V_2. The resonant voltage step-up in the series circuit tends to compensate for the drop in gain from V_1 due to the reduced size of the plate load.

In servicing amplifiers where peaking coils are used, sometimes you may suspect that a peaking coil is open. If you check across the peaking coil with an ohmmeter, you should get a resistance reading of only a few ohms. If you get a resistance reading of several thousand ohms it indicates that the coil is open and that you are reading through the resistor on which the peaking coil is wound. Usually when a peaking coil is open, it is open right at the end of the coil where the coil is connected to the resistor lead. If you can find the place where the coil connects to the resistor lead, resolder it and if the connection is poor this should clear up the trouble. If on the other hand, it doesn't clear up the trouble, sometimes you can find the wire going from the resistor lead to the coil and see where it is broken. If there isn't enough wire to stretch over to make a connection to the resistor lead, unwinding one turn of the coil will usually enable you to make the connection. Taking a single turn off the coil will not affect its inductance enough to upset its performance in the circuit.

Shunt-Series Peaking. The most satisfactory peaking arrangement is a combination of both shunt and series peaking. You'll find this type of peaking is widely used in the video amplifiers of television

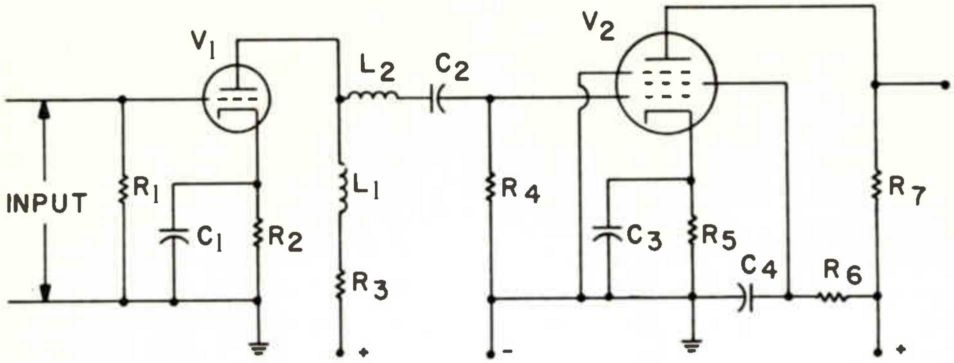


Fig. 10. A shunt-series compensated amplifier.

receivers and in other amplifiers where a wide frequency response is required. The schematic diagram of an amplifier using series-shunt peaking is shown in Fig. 10. This is the same basic amplifier circuit that we started with in Fig. 3, but the shunt-peaking coil, L_1, and the series-peaking coil, L_2, have been added.

An equivalent circuit of the coupling network is shown in Fig. 11. Notice that in the previous case where we used shunt peaking alone, the coil L_1 forms a parallel resonant circuit. However, this time instead of forming a parallel-resonant circuit with the entire capacity in the circuit, it forms a parallel-resonant circuit with the output capacity of V_1. The peaking coil L_2 effectively separates the output capacity of V_1 from the input capacity of V_2. L_2 forms a series-resonant circuit with the input capacity of V_2.

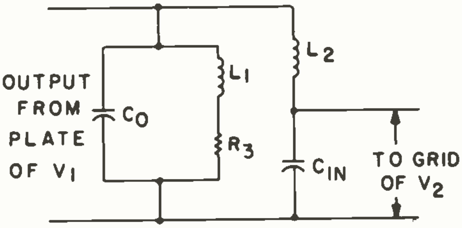


Fig. 11. Equivalent circuit of coupling network in Fig. 10.

By using the series-peaking coil L_2 in this way, we have less capacity in the plate circuit of V_1. This often enables us to increase the size of R_3 which will increase the gain at low and middle frequencies. At the same time, by using the shunt-peaking coil L_1, we can increase the gain of the amplifier at the higher frequencies where it would normally start to fall off. Thus we can maintain a constant output voltage from V_1 over a wider frequency range.

The series-peaking coil, L_2, in addition to separating the output capacity of V_1 from the input capacity of V_2, also forms a series-resonant circuit with the input capacity of V_2. Therefore, as the output signal starts to fall off from V_1, the resonant circuit made up of L_2 and the input capacity of V_2 takes over, and by means of the resonant voltage step-up can keep the signal fed to the grid of V_2 essentially constant.

In circuits using both series and shunt peaking we can select the values of the

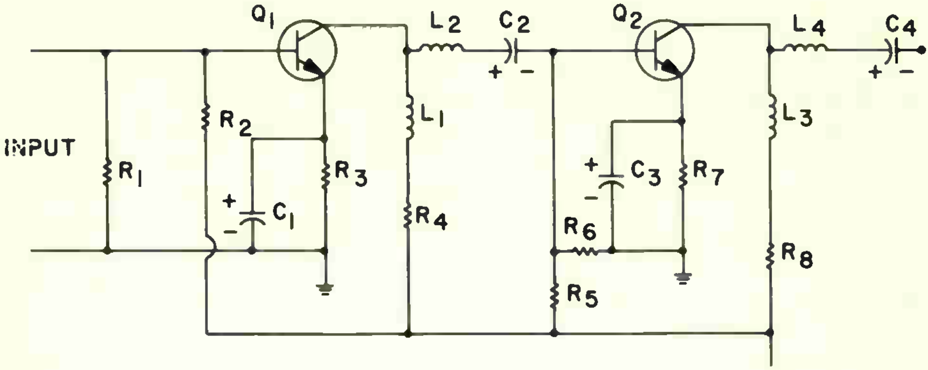


Fig. 12. A series-shunt compensated transistor amplifier.

peaking coils so the resonant circuits resonate at slightly different frequencies. Thus it is possible to make one resonant circuit take over (usually the parallel-resonant circuit) when the gain of the amplifier first starts to fall off. At a frequency above the resonant frequency of the parallel-resonant, the series circuit becomes resonant and compensates for the drop in impedance in the plate circuit of V_1 above the resonant frequency of the shunt-peaking circuit. Thus by using a combination of shunt and series peaking it is usually possible to get more gain from the amplifier over this entire bandwidth because we can use a larger value of load resistor, and also it is easier to extend the high-frequency response of the amplifier and maintain the response essentially flat over a wider frequency range.

TRANSISTOR AMPLIFIERS

So far in our discussion we have been talking about extending the high-frequency response of tube amplifiers. Essentially the same problems exist in transistor amplifiers as exist in tube amplifiers. The output capacity of one transistor, the input capacity of the second transistor, and the stray capacity in the coupling network coupling the two transistors together, limits the high frequency response of the amplifier.

A typical two-stage series-shunt compensated transistor amplifier is shown in Fig. 12. Notice that we have a shunt-peaking coil, L_1, in the collector circuit of Q_1. We have a series-peaking coil connected between the collector of Q_1 and the coupling capacitor C_2. The equivalent circuit of the coupling network used between Q_1 and Q_2 at high frequencies, where the capacity of C_2 can be ignored, is shown in Fig. 13. Notice that we have essentially the same circuit

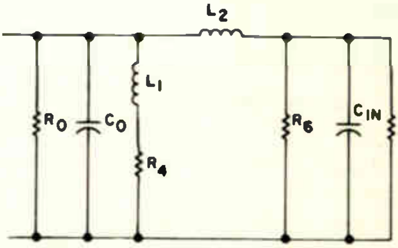


Fig. 13. The high-frequency equivalent of the coupling network used in Fig. 12.

as we had in the series-shunt compensated vacuum-tube coupling circuit except for the resistors R_O and R_{in}. R_O represents the output resistance of Q_1 and R_{in}, the input resistance of Q_2. In the tube circuit, these resistances were so high they could be ignored. However, in transistors, these resistances are low and must be considered.

The peaking coil L_2 separates the output capacity of Q_1 and the associated capacity of the circuit from the input capacity of Q_2 and its associated stray capacity. L_2 is selected to resonate with the capacity in the input circuit of Q_2 and form a series-resonant circuit in order to peak the input to Q_2 at the frequency desired. At the same time, L_1 forms a parallel-resonant circuit in the collector circuit of Q_1 and helps keep the output from Q_1 up at higher frequencies.

We mentioned earlier that the collector load resistor, R_4, is in parallel with the input resistance of Q_2. You will remember from your study of low-frequency voltage amplifiers, that in a transistor circuit Q_2 has a certain base current. This lowers the effective input resistance of the second transistor amplifier, and since this is in effect in parallel with R_4, it has the effect of lowering the value of the collector load resistor in the collector circuit of Q_1. Therefore we already have a comparatively low collector load resistor and there is a limit to how far we can reduce this resistor in order to level out the response of the coupling network over a wide frequency range. You will remember that in the vacuum-tube coupling network we were able to drop the value of the plate load resistor in the first stage and in so doing bring down the low and middle-frequency gain of the amplifier. At the same time, we extended the frequency at which the gain of the amplifier begins to drop off appreciably. Since the collector load resistor is in effect already low, we cannot lower it much further. Fortunately, since the load resistor is low, it takes a higher shunt capacity to have an appreciable effect at high frequencies. Therefore the transistor coupling network tends to give equal response at a higher frequency even without the peaking coils in the circuit than in the case of a vacuum-tube network.

The output of Q_2 may be connected to another amplifier stage, or in a television receiver it might be connected to the picture tube. Additional peaking will be used in the output circuit of this stage in order to keep up the high-frequency response in this circuit. L_3 is a shunt-peaking coil, and L_4 a series-peaking coil as in the network between Q_1 and Q_2.

We run into an additional problem in transistor amplifiers at high frequencies that we do not encounter in vacuum-tube amplifiers. In a common-emitter circuit such as used for Q_1 and Q_2 in Fig. 12, we normally have a 180° phase shift in each stage. You will remember that when the input signal fed to Q_1 drives the base in a positive direction, it increases the forward bias across the emitter-base junction of the NPN transistor. This causes the number of electrons crossing the emitter-base junction to increase and hence the number of electrons reaching the collector will increase. When the number of electrons reaching the collector and flowing through L_1 and R_4 increases, this will cause the voltage drop across R_4 to increase. Therefore the voltage at the collector will swing in a negative direction. Thus with the input signal as shown in Fig. 14A, the collector voltage swings in the opposite direction as shown in Fig. 14B. We say the two signals are 180° out-of-phase.

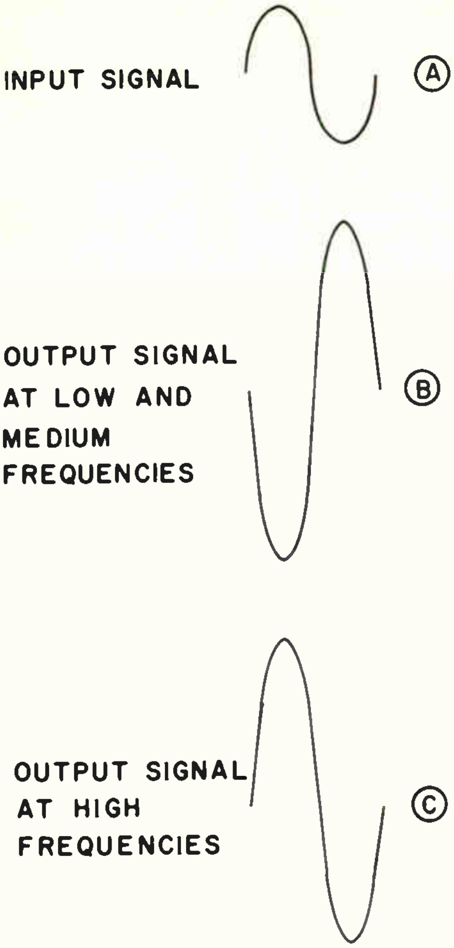


Fig. 14. Phase relationships between input and output signals at low, medium and high frequencies in common emitter amplifiers.

The base of a germanium transistor is usually about one thousandth of an inch thick. The base of a silicon transistor is about one ten-thousandth of an inch thick. It takes the electrons a certain length of time to cross the base of the transistor. It will take the electrons longer to cross the base of the germanium transistor because it is thicker than the silicon transistor. Therefore consider what can happen when the time it takes the electrons to travel through the base is considered. If the signal applied to the base is a low-frequency signal or a medium-frequency signal, the time it takes the electrons to cross the base compared to the time of one cycle is relatively short. The output signal will be 180° out-of-phase with the input signal as shown in A and B of Fig. 14. However, at high frequencies, the electrons may be delayed sufficiently in travelling through the base of the transistor to cause a phase shift between the output signal voltage at medium and low frequencies and the output signal voltage at high frequencies. As a matter of fact, at some high frequency it will take the electrons so long to cross the base that instead of the signals being 180° out-of-phase, they will be in-phase because the electrons are delayed by one half cycle in travelling through the base region. When this happens, the output voltage in the collector circuit of Q_1 will be in-phase with the input voltage applied to the base of Q_1.

You will remember that in a transistor there is a capacity between the collector and the base. A signal is fed from the collector of the transistor back to the base through this capacity. When the output signal is 180° out-of-phase with the input signal, the signal fed back to the base through the collector-base capacity, simply reduces the amplitude of the input signal. This is a form of degeneration; the output from the transistor would not be as high as it would be without this feedback signal. However, at high frequencies where the output signal may be in-phase with the input signal, the signal fed from the collector back to the base will be in-phase with the input signal. This will reinforce the input signal which in turn produces a higher amplitude output signal which in turn builds up the input signal still further. Thus the transistor may go into oscillation and the output signal fed back to the input circuit will take control of the transistor so that it begins producing a high-frequency signal without any input. In circuits where there is a possibility of oscillation occurring, some kind of neutralization must be employed so that a signal that is 180° out-of-phase with the feedback signal, can be fed back into the base circuit to cancel out the signal fed from the collector back to the base through the collector-base capacitance.

FIELD-EFFECT TRANSISTORS

Both the junction-type and the insulated-gate field-effect transistors can be used in wide-band amplifiers. The problems in an amplifier using field-effect transistors are almost identical to those encountered in equipment using vacuum tubes. The output capacity of the first stage plus the input capacity of the second stage along with stray wiring capacity tend to limit the high-frequency response of the amplifier.

A typical two-stage compensated amplifier using junction-type field-effect transistors is shown in Fig. 15. Notice the similarity between this and a vacuum-tube two-stage amplifier.

The peaking coil L_1 in the drain circuit of Q_1 is used to form a parallel-resonant circuit in the drain circuit, to keep the output from Q_1 from falling off at high frequencies. The series-peaking coil L_2 is used to resonate with the input capacity of Q_2 to form a series-resonant circuit to keep up the amplitude of the high-frequency signals fed to the gate of Q_2. In the output circuit of Q_2 we have shown series peaking used between the drain and the following stage.

In many amplifiers using field-effect transistors you will find that series peaking only is used. The one type of peaking is frequently all that is required to obtain the high frequency response required. The value of the resistor R_3, in the drain circuit of Q_1, may be reduced in order to

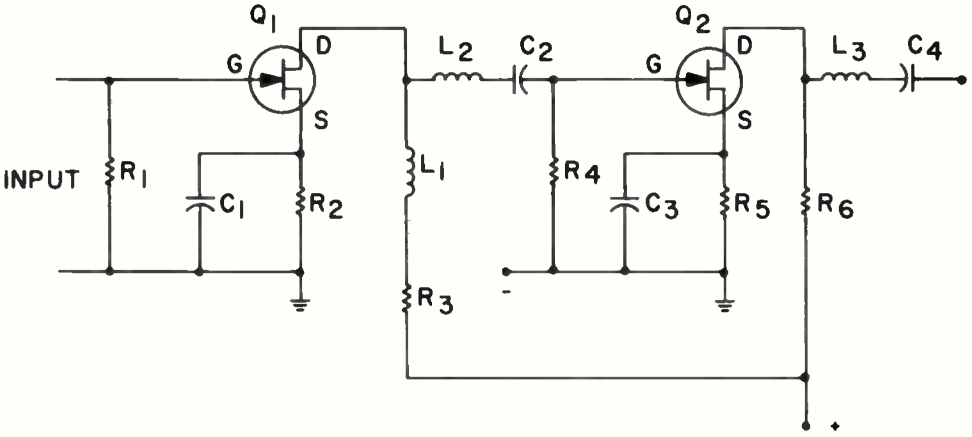


Fig. 15. Compensated amplifier using field-effect transistors.

increase the frequency at which the capacity shunting the output of Q_1 begins to have an appreciable effect on the impedance of the drain circuit of Q_1. You have essentially the same situation as you had with the resistor in the plate circuit of a tube-type amplifier. Reducing the size of the resistor increases the frequency at which the reactance of the output capacitance becomes equal to the resistance of the resistor.

One of the big advantages of the field-effect transistor is that it has a high input resistance. Therefore, the input resistance of Q_2 has little or no loading effect on the output resistance of Q_1. In fact, as far as the performance of the circuit is concerned, it is practically identical to the performance of a two-stage vacuum tube amplifier. Field-effect transistors are able to combine most of the advantages of vacuum tubes along with most of the advantages of transistors and should become increasingly important in the future in electronic equipment.

SELF-TEST QUESTIONS

(l) Why is the value of the plate-load resistor in a wide-band amplifier kept low?

(m) Why is there a limit to the size of grid resistor that can be used in a vacuum-tube amplifier?

(n) How does L_1 in the circuit shown in Fig. 5 help improve the high-frequency response of the amplifier?

(o) How does the peaking coil L_1 in the circuit shown in Fig. 8 help improve the high-frequency response of the amplifier?

(p) What do we mean by series-shunt peaking?

(q) Does capacity shunting have as great an effect on high-frequency response in transistor amplifiers as it does in vacuum-tube amplifiers?

(r) Are there any problems encountered at high frequencies in transistor amplifiers that are not likely to be encountered in vacuum-tube amplifiers?

(s) Are the high-frequency problems encountered in field-effect transistors more like those encountered in vacuum tubes or like those encountered in bipolar transistors?

Extending the Low-Frequency Response of an Amplifier

You will remember that when we studied low-frequency amplifiers we pointed out that the output from an amplifier falls off at low frequencies as well as at high frequencies. The low-frequency response of an amplifier falls off for several reasons. One reason is the reactance of the coupling capacitor used to couple the two stages together increases as the frequency decreases. At some low frequency, the reactance of the capacitor will become so high that it will act like a voltage divider along with the input resistance in the second stage of the amplifier. Thus not all of the amplified signal produced by the first stage is fed to the input of the second stage.

In Fig. 16 we have shown schematic diagrams of three R-C coupled amplifiers. The circuit shown in A is made up of two vacuum tubes, the one at B has two transistors and the one at C has two

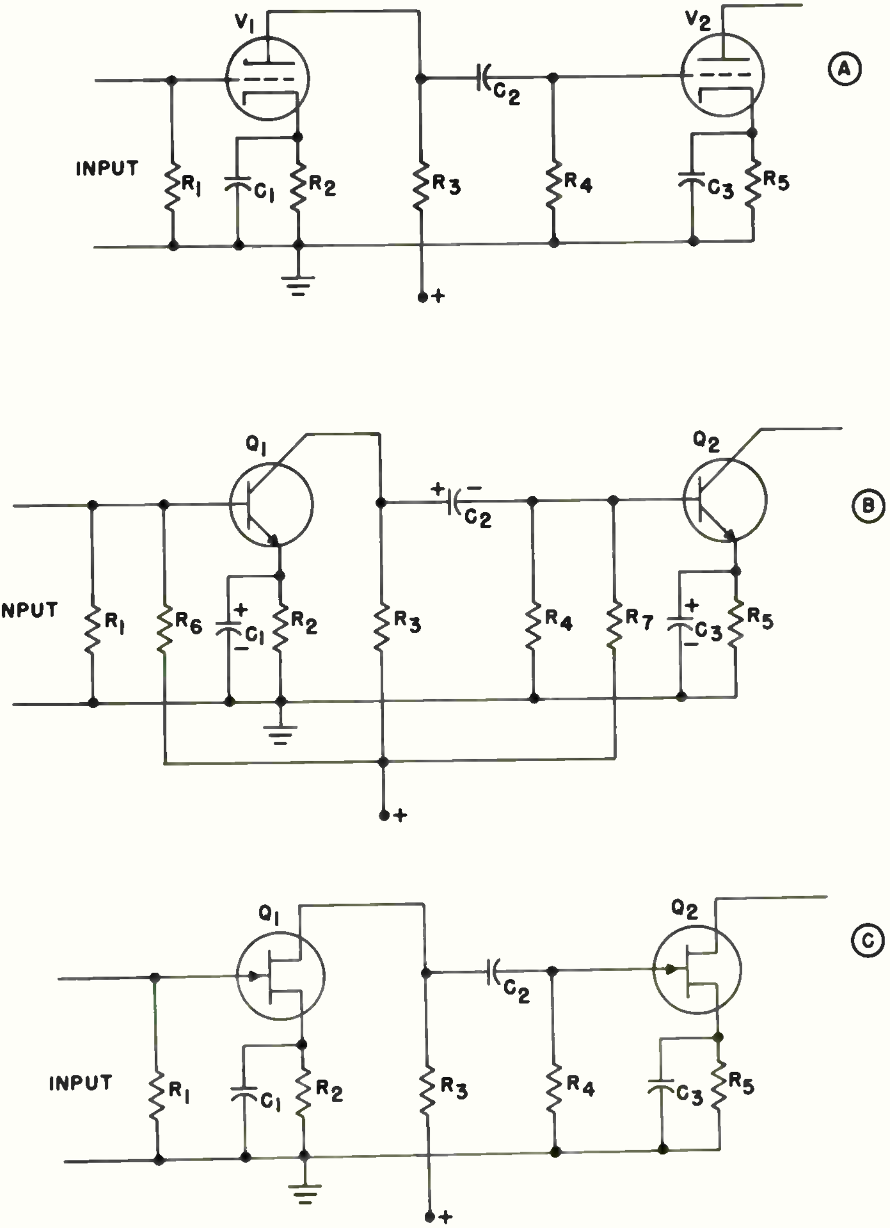


Fig. 16. Basic R-C coupled amplifiers.

field-effect transistors. In each case C_2 is the coupling capacitor between the two stages. The reactance of this capacitor will at some low frequency become equal to the input resistance in the following stage. When this happens, only 70.7% of the voltage developed in the output of the first stage will be fed to the input of the second stage. At lower frequencies, the amount of signal developed by the first stage that reaches the second stage will become increasingly smaller.

In the case of the vacuum-tube amplifier shown in Fig. 16A we can use a large value of grid resistance, R_4, in the input of the second stage. By using as large a resistance as possible in this circuit, we can reduce to a low value the frequency at which the reactance of C_2 becomes equal to the resistance of R_4. In the case of the transistor amplifier shown in Fig. 16B, however, there is not much we can do about increasing the value of the base resistor R_4. The transistor itself draws a certain base current. Thus the transistor itself has a low input resistance. Therefore, this resistance is always in parallel with R_4 and increasing the value of R_4 will have little effect on increasing the actual input resistance of Q_2. We get around the low input resistance of Q_2 by using a high capacity electrolytic capacitor between Q_1 and Q_2 as the coupling capacitor. Since transistors are operated at relatively low voltages we can use a capacitor with quite a high capacity, and still keep the physical size of the capacitor quite small.

In the field-effect transistor circuit shown in Fig. 16C, once again we can increase the value of R_4, the resistance between the gate of Q_2 and the source, to as high a value as possible. Since there is little or no gate current in a field-effect transistor the value of R_4 can be made quite large and increase the input resistance of the second stage. Thus the low-frequency limit of the amplifier can be extended to quite a low value. This is particularly true in the case of the insulated-gate field-effect transistor, since for all practical purposes there is no gate current at all in these transistors.

REDUCING THE EFFECT OF THE COUPLING CAPACITOR

The equivalent circuit of the coupling network used between the two stages in each of the examples shown in Fig. 16 can be redrawn as shown in Fig. 17. In the case of Fig. 16A, using the two vacuum tubes, R_3 is the plate load resistor of V_1, and R_4 is the grid resistor of V_2. In the case of the transistor circuit shown in Fig. 16B, R_3 is the collector resistor of Q_1. R_4 is the resistor connected between the base of Q_2 and ground. In the case of the circuit shown in Fig. 16C where we've used the field-effect transistors, R_3 is the resistor connected between the drain of Q_1 and B+, and R_4 is the resistor connected between the gate of Q_2 and ground.

You can readily see from the circuit shown in Fig. 17 that the output voltage developed at the output of the first stage

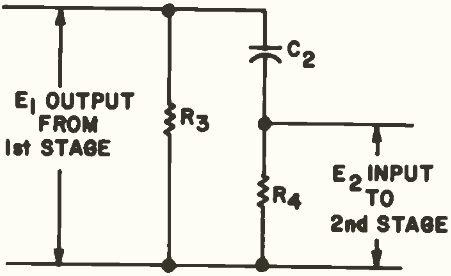


Fig. 17. Equivalent circuit of coupling network at low frequencies.

is fed to the series combination of C_2 and R_4. At high frequencies and middle frequencies, the capacitive reactance of C_2 is so small compared to the resistance of R_4 that practically all of the signal developed at the output of the first stage is fed to the input of the second stage. For all practical purposes, C_2 simply acts like a short circuit.

However, at lower frequencies, the reactance of C_2 begins to become appreciable and it cannot be ignored. At some low frequency, the reactance of C_2 will become equal to the resistance of R_4. Since we have equal capacitive reactance and resistance in this circuit, we will have a current flowing that leads the voltage applied by 45°. Furthermore, since the voltage across C_2 plus the voltage across R_4 must be equal to the voltage across R_3, we have a drop in the voltage across R_4. This means that the voltage applied to the input of the second stage decreases and at the same time we have a phase shift.

The relationship between the output voltage of the first stage which we have labeled E_1, and the input voltage applied to the second stage, which we have labeled E_2, can be seen from the vector diagram of Fig. 18. Notice first, that the voltage E_2 is in-phase with the current I. This is as we might expect because in a resistance, the voltage and current are always in-phase. Therefore the voltage E_2 leads the voltage E_1 by 45°. Notice also that the voltage E_C, which is the voltage across the capacitor, is equal to the voltage E_2. The vector sum of the voltage E_2 and E_C will be equal to the voltage of E_1.

Not only is the drop in voltage across R_4 important, because this will reduce the amplitude of low-frequency signals, but in many applications, the phase shift is just as big a problem. This is particularly true in video amplifiers in television receivers. They must be able to handle very low-frequency signals without any attenuation or phase shift. A phase shift will displace the video information in part of the picture and cause smearing. Therefore it is desirable to keep the drop in low-frequency response and the phase shift as low as possible.

Obviously one of the simplest ways of preventing problems of low frequencies is to use a large value of coupling capacitor. We do this when we design an amplifier to have good low-frequency response. However, in most cases, where you are interested in the low-frequency response of an amplifier, you are also interested in the high-frequency response. Large capacitors also have a higher capacity to ground. Thus there is a limit to how large a coupling capacitor you can use to improve the low-frequency response with-

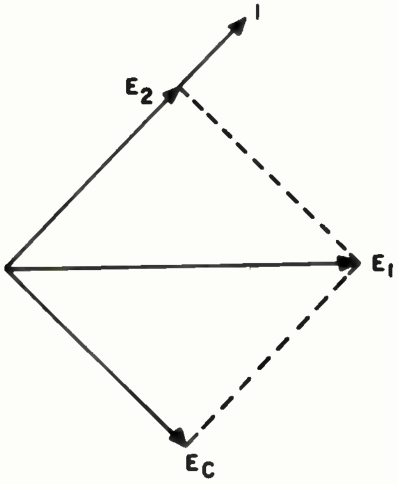


Fig. 18. Vector diagram of voltages at output of first stage and input of second stage.

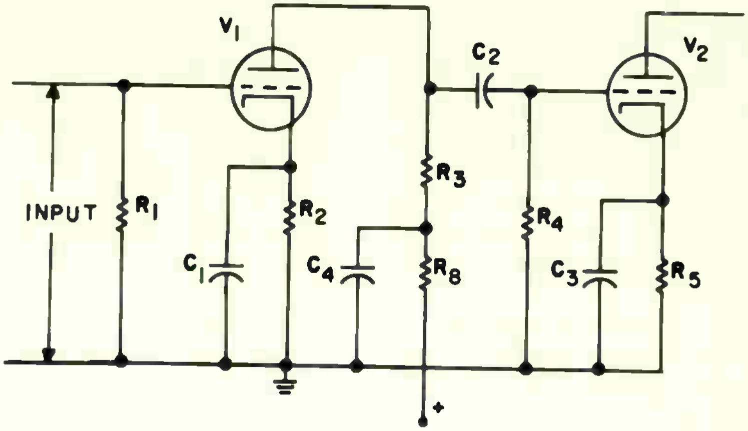


Fig. 19. A two stage amplifier with low-frequency compensation in the plate circuit of V_1.

out running into problems with the high-frequency response. Therefore while we can improve the low-frequency response, to some extent, by using a large coupling capacitor, there is a limit as to how far we can go.

LOW-FREQUENCY COMPENSATION

Regardless of how large a coupling capacitor and of how large a resistance we are able to put into the input of the second stage, the reactance of the capacitor will still increase as the frequency decreases. In some amplifiers where we must amplify very low frequencies of only a few Hertz, with essentially the same gain that we have in the middle-frequency range, we usually have to add something to the circuit to compensate for the fact that the coupling capacitor reactance becomes appreciable at these low frequencies.

In Fig. 19 we have shown how an additional resistor and capacitor can be added in the plate circuit of V_1 in the amplifier shown in Fig. 16A, to compensate for an increase in the reactance of C_2 at low frequencies. In this circuit, the low-frequency compensating network that has been added consists of R_8 and C_4. Let's see how the addition of these two components can improve the gain of the amplifier at low frequencies.

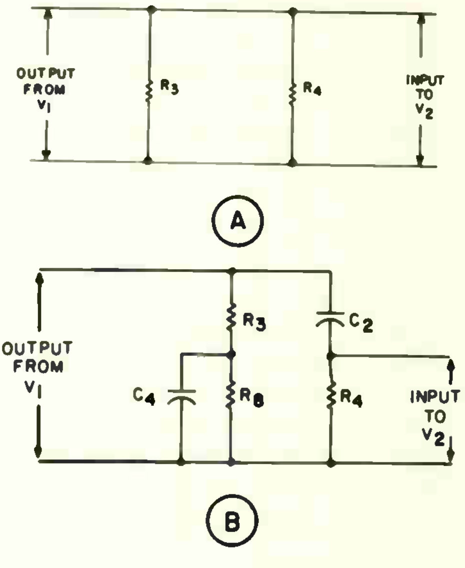


Fig. 20. Equivalent circuit of low-frequency compensation network. "A" is for middle and high frequencies. "B" is for low frequencies.

In Fig. 20A we have shown the equivalent circuit of the coupling network between V_1 and V_2 and the low frequency compensation network at middle and high frequencies. Notice that we have omitted C_2 because in the middle-frequency range, the reactance of C_2 is so low that it can be ignored. Also the value of C_4 is selected so that in the middle and higher frequencies its reactance is very low. It is so low that the end of R_3 that connects to the junction of C_4 and R_8 is in effect connected to ground through C_4. This places R_3 and R_4 directly in parallel. The parallel resistances of these two resistors is the plate load of V_1.

As we pointed out previously, in most amplifiers where we are interested in good low-frequency response we are also interested in good high-frequency response. You will remember that we are going to use a low value plate-load resistor in order to improve the high-frequency response. Therefore, R_3 in Fig. 19 will be a low value resistor. Since at the middle frequencies, R_3 is in effect in parallel with R_4, and R_4 will be many times the value of R_3, the plate load is in effect R_3 alone. For all practical purposes we could omit R_4 in the equivalent circuit shown in Fig. 20A.

At low frequencies, the reactance of C_2 becomes appreciable and it cannot be ignored. At the same time, the reactance of C_4 also becomes appreciable so that it no longer effectively grounds the one end of R_3. Therefore, the plate load for V_1 becomes the combination of R_3 in-series with the parallel combination of R_8 and C_4. In other words, the plate load resistance of V_1 increases. When the plate load of the tube increases, the voltage developed in the plate circuit will increase and this compensates for the loss in voltage across the coupling capacitor C_2.

Not only does the compensating network compensate for the drop in voltage fed to the input of the second stage, but it also improves on the phase shift that occurs at low frequencies. Let's consider how this can happen.

Going back to the equivalent circuit shown in Fig. 20A, remember that the signal current from the vacuum tube develops the voltage across R_3, in other words, across the plate load resistance. This voltage in turn causes a current to flow across the coupling capacitor C_2 and the grid resistor R_4 developing a voltage across R_4. Now consider what happens in the equivalent shown in Fig. 20B. The signal current from the tube flows through the plate load consisting of R_3 in series with the parallel combination of R_8 and C_4. Since the circuit is a capacitive circuit, the voltage developed across this circuit will lag the current. Thus we have a low frequency signal voltage in the plate circuit of V_1 that is lagging the signal current. This lagging signal voltage causes a current to flow through C_2 and R_4. Since the circuit consisting of C_2 and R_4 is capacitive, the current flowing will lead the voltage. By the proper selection of C_4 and R_8 we can cause the phase shift in this network to equal or compensate for the phase shift in the network consisting of C_2 and R_4. Therefore the current flowing through C_2 and R_4 will be in-phase with the signal current supplied by the tube. This means that the signal voltage developed across R_4 will then be in-phase with the signal current supplied by the tube at low frequencies. Since it is already in-phase with the signal current at middle and high frequencies we have compensated for the low-frequency phase shift.

Low-frequency compensation can also be used in circuits where transistors or

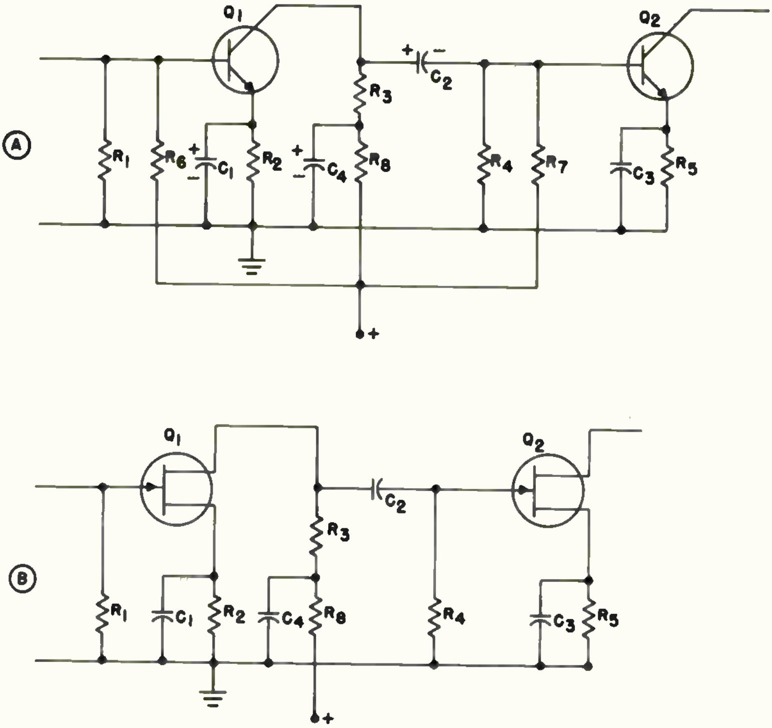


Fig. 21. Low-frequency compensation is shown in a transistor amplifier at A, and in a field-effect transistor amplifier in B.

field-effect transistors have been employed. In the circuit shown in Fig. 21A, we have shown low-frequency compensation in the collector circuit of Q_1. Notice that once again we have added the resistor R_8 in series with the collector-load resistor R_3 and the additional capacitor C_4 in the collector circuit. Low-frequency compensation is not as effective in transistor amplifiers as in vacuum-tube amplifiers.

In the diagram shown in Fig. 21B, we have added low-frequency compensation to the amplifier using field-effect transistors. The additional resistor R_8 is added in the drain circuit of Q_1 along with the additional capacitor C_4. The operation of these low-frequency compensating circuits is exactly the same as in the case of the low-frequency compensating circuit in the vacuum-tube amplifier and is equally effective.

LOW-FREQUENCY DEGENERATION

Going back to the amplifiers shown in Fig. 16, in addition to the coupling capacitor C_2, the bypass capacitors C_1 and C_3 may cause a drop in the low-frequency response. Considering first the vacuum-tube amplifier shown in Fig. 16A, C_1 is the cathode bypass for V_1. The purpose is to maintain the cathode voltage on V_1 constant. At medium and high-frequencies it acts as a bypass capacitor so that the signal current in effect flows through it and R_2 is effectively bypassed. Therefore the voltage across R_2 remains constant. However, at low frequencies, the reactance of C_1 increases. As a result, part of the signal current flows through R_2. This causes a signal voltage to appear at the cathode that is in-phase with the voltage applied to the grid of the tube. This reduces the grid-to-cathode signal voltage so that the output from the stage goes down. This effect can be kept at a minimum by using a large capacitor, usually an electrolytic capacitor, to provide effective bypassing at low frequencies. Another method of eliminating this problem is to eliminate the bypass capacitor altogether. This will reduce the gain of the stage at medium frequencies as well as high frequencies, but the degenerative effect of the unbypassed cathode is constant at all frequencies. Thus the gain of the stage is reduced an equal amount at all frequencies rather than at low frequencies only.

Exactly the same situation exists in the case of the emitter bypass capacitor C_1 in the transistor amplifier circuit shown in Fig. 16B, and the source bypass capacitor C_1 in the field-effect transistor circuit shown in Fig. 16C. These capacitors become degenerative at low frequencies and will reduce the low-frequency response of the stage. By using large electrolytic capacitors the effect can be kept at a minimum so that the response of the amplifier may be satisfactory down to a frequency of only a very few cycles per second. Also the bypass capacitor may be omitted, as in the case of the tube amplifier, introducing a degenerative effect at all frequencies so as to level off the response of the amplifier.

SELF-TEST QUESTIONS

(t) What part is the primary cause of poor low-frequency response in a two-stage amplifier?

(u) In addition to a drop in gain at low frequencies, what other problem is frequently encountered?

(v) What method is used to improve the low-frequency response of amplifiers?

(w) Is low-frequency compensation equally effective in vacuum-tube and transistor-amplifier circuits?

(x) Is low-frequency compensation effective in improving the low-frequency response in an amplifier using field-effect transistors?

(y) What do we mean by cathode degeneration?

Typical Wide-Band Amplifiers

In this section of the lesson we will look at a few typical wide-band amplifiers such as you might encounter in electronic equipment. We will also discuss printed circuit wiring since the trend today in modern electronic equipment is to use printed circuit wiring. This type of wiring is particularly advantageous in wide-band amplifiers because the stray capacities in the circuit can be kept constant from one amplifier to another, and therefore it is quite easy to manufacture amplifiers with almost identical characteristics.

In transistorized equipment, as we mentioned previously, it is not quite as easy to compensate for high-frequency losses as it is in vacuum-tube amplifiers. Therefore we will look at some circuits found only in transistorized equipment that get around some of these disadvantages.

In the preceding section of the lesson we discussed low-frequency compensation. As you will remember, low-frequency compensation is needed primarily because the reactance of the coupling capacitor between stages increases as the frequency goes down. This problem can be overcome by the use of direct coupling; in this type of coupling, the capacitor is omitted entirely and hence any problems created by it are avoided. We will look at direct-coupled amplifiers so you will be familiar with this type of circuit.

There is no doubt that television receivers make more use of wide-band amplifiers than any other electronic equipment. This is simply due to the fact that there are so many television receivers manufactured every year. Therefore we'll start our study of typical wide-band amplifiers with a look at a typical video amplifier which is a wide-band amplifier.

A TYPICAL VIDEO AMPLIFIER

In Fig. 22 we have shown the sche-

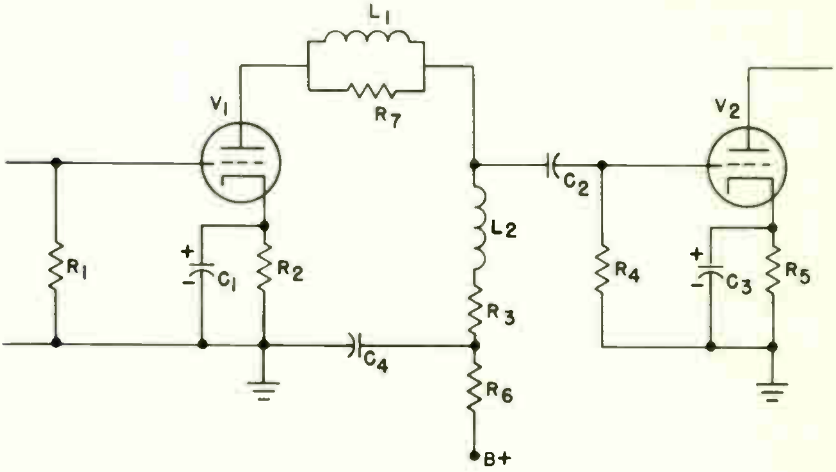


Fig. 22. A typical wide-band amplifier.

matic diagram of a typical wide-band amplifier such as might be used for video amplification in a television receiver. Notice that to improve the high-frequency response of the amplifier both series and shunt peaking have been used. Notice that across the series-peaking coil L_1, we have a shunt resistor. This is to reduce the Q of the coil and prevent oscillation, and at the same time broaden the response of the series-resonant circuit.

L_2 is a shunt-peaking coil and is used to form a parallel-resonant circuit to increase the value of the plate load at high frequencies.

Low-frequency compensation is provided by C_4 and R_6 connected in the plate circuit of V_1. This is similar to the low-frequency compensating network shown earlier. We have shown electrolytic capacitors in the cathode circuits of both stages as the cathode bypass capacitors. You can tell from the schematic when an electrolytic capacitor is used because the polarity of the capacitor is usually indicated. Notice that the polarity signs indicate that the positive side of the capacitor is connected to the cathode of the tube and the other side to ground. Electrons flow from ground through the cathode resistor to the cathode of the tube, and in so doing develop a voltage across the bias resistor having a polarity such that the cathode end is positive. The electrolytic capacitors must be connected with this polarity.

In some wide-band amplifiers, electrolytic cathode bypass capacitors may be shunted by small paper capacitors or ceramic capacitors. You might find a bypass cathode capacitor with a capacity of about 100 mfd shunted by a .001 mfd ceramic capacitor. This is often done because electrolytic capacitors are sometimes rather poor bypass capacitors at high frequencies. Therefore at low frequencies the electrolytic capacitor acts as the bypass capacitor, but at high frequencies where the electrolytic becomes a rather inefficient bypass, the ceramic capacitor has a low enough reactance to bypass the cathode resistor effectively.

TRANSISTOR WIDE-BAND AMPLIFIERS

A transistor video amplifier using PNP transistors is shown in Fig. 23. L_1 is the

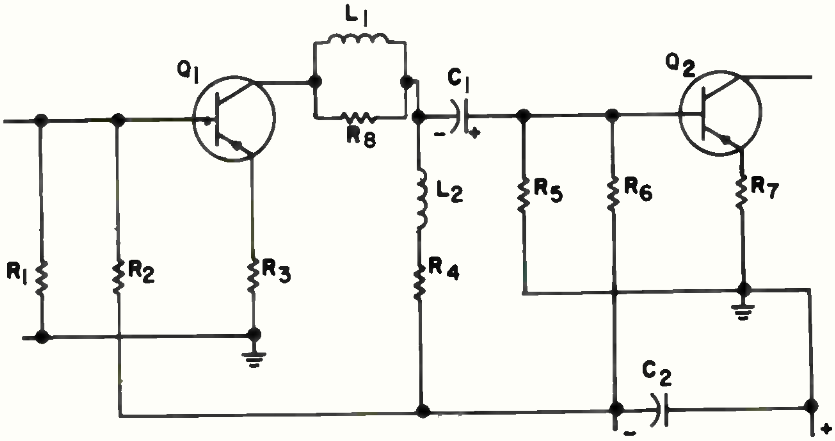


Fig. 23. A transistor wide-band amplifier.

series-peaking coil, and it is loaded by R_8 to reduce the Q of the coil and broaden the response of the circuit. L_2 is the shunt-peaking coil.

The coupling capacitor C_1 is an electrolytic capacitor; a large value of capacitor is used to provide the required low-frequency response. Notice that the emitter resistors R_3 and R_7 are not bypassed. In order to prevent low-frequency degeneration due to the reactance of bypass capacitors across the emitter resistors, the capacitors are simply omitted. As we mentioned previously this introduces degeneration at all frequencies but tends to flatten the gain of the amplifier.

Feedback Circuits. Transistor amplifiers do not lend themselves to improving frequency response by means of peaking coils nearly as well as do vacuum-tube amplifiers. The same is true of improving the low-frequency response; increasing the size of the base resistor of the second stage in a transistor amplifier actually has little effect on the input resistance of the stage. The base current of the transistor primarily determines the input resistance.

In the case of the equivalent coupling circuit for the low-frequency response shown in Fig. 17, in a transistor amplifier R_3 and R_4 are actually shunted by other resistors that should be considered. R_3 is shunted by a resistance which is the output resistance of Q_1, and R_4 is shunted by a resistance which is the input resistance of Q_2. The output resistance of a transistor in a common-emitter circuit is probably around 20,000 ohms whereas the input resistance of a common-emitter circuit is quite low, usually in the vicinity of a few hundred ohms at the most.

The frequency response of transistor amplifiers can frequently be improved by means of feedback circuits. Feedback, of course, must be degenerative feedback and it operates on the principle that as the output signal from the amplifier increases, the amount of feedback must increase. This in turn will tend to reduce the overall gain of the amplifier more at a frequency where the output is higher than it would at another frequency where the output signal is low, and hence the feedback signal is low.

In Fig. 24 we have shown the sche-

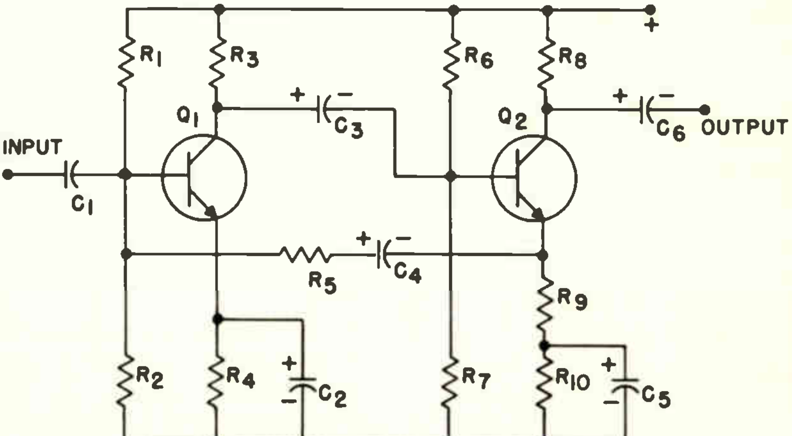


Fig. 24. Improving the frequency response by means of feedback.

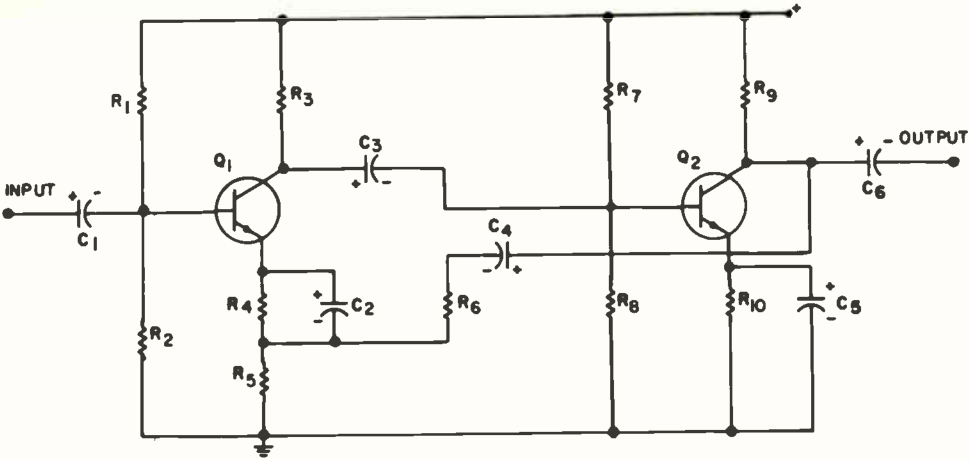


Fig. 25. A second feedback circuit.

matic diagram of a circuit that could be used to improve the frequency response of a two-stage transistor amplifier. The circuit is quite similar to the transistor amplifier shown previously except that the feedback network consists of C_4 and R_5. This provides negative feedback back from the emitter of Q_2 back to the base of Q_1.

Consider what happens as a signal passes through the amplifier. When the signal applied to the base of Q_1 swings in a positive direction, the forward bias across the emitter-base junction of Q_1 will be increased. This will cause the current through the transistor to increase and hence the voltage drop across R_3 will increase. As the voltage drop across R_3 increases, the signal voltage at the collector of Q_1 will swing in a negative direction. Thus for a positive input signal we have an amplified negative signal in the output of Q_1.

The negative signal from Q_1 is fed to the base of Q_2 through the coupling capacitor C_3. The negative-going signal reduces the forward bias across the emitter-base junction of Q_2. Thus the current flowing through Q_2 decreases. When this happens the voltage drop across the emitter resistor R_9 will decrease. The voltage across R_{10} is held essentially constant by C_5. The decrease in signal voltage across R_9 is actually a negative signal. This negative signal is fed through C_4 and R_5 back into the base of Q_1 and subtracts from the original positive signal.

In this circuit, as the gain tends to rise at middle frequencies, the amount of signal fed back from the emitter of Q_2 to the base of Q_1 increases thus tending to reduce the overall gain of the amplifier. On the other hand, if the signal starts to fall off at the high frequencies or at the low frequencies, any amount of feedback will also go down so that the overall gain of the two-stage amplifier will tend to increase.

Another example of feedback which is used to improve the frequency response of a transistor is shown in Fig. 25. Here the signal feedback is taken from the collector of the second transistor Q_2 and fed through a resistor-capacitor network back into the emitter of the first transistor Q_1. To see how this feedback circuit works, let's follow the signal phases through the amplifier.

When a signal drives the base of Q_1 in a positive direction, current through the transistor increases causing a voltage drop across the collector-load resistor R_3 to increase. When this voltage drop increases, the net voltage between the collector of Q_1 and ground swings in a negative direction. Thus in the common-emitter circuit, we always have the situation of a 180° phase shift between the input and output signals. Now the negative-going signal is fed from C_3 to the base of Q_2 and this causes the current through Q_2 to decrease. When the current through Q_2 decreases, the voltage drop across R_9 decreases causing the collector of Q_2 to swing in a positive direction. Once again we have the 180° phase shift in the common-emitter circuit so that we have a positive-going signal produced in the collector circuit of Q_2.

This positive signal is then fed through C_4 and R_6 into the emitter circuit of Q_1. The resistors R_6 and R_5 actually act as a voltage-divider network so that the portion of the signal developed across R_5 will be fed into the emitter circuit of Q_1. Thus when the signal applied to the base of Q_1 swings in a positive direction we also have the emitter of Q_1 swinging in a positive direction due to the feedback signal. This reduces the net base-to-emitter signal voltage so that the increase in current through Q_1 will not be as great as it would be without the feedback.

As in the case of the previous amplifier, when the output from Q_2 begins to increase, the amplitude of the feedback signal will also increase and this in turn tends to reduce the gain of the amplifier to keep the output constant. On the other hand, if the output of Q_2 begins to fall off, then the amount of feedback voltage goes down so that the gain of the amplifier tends to increase and thus level off the overall frequency response of the amplifier.

DIRECT-COUPLED AMPLIFIERS

All of the problems introduced by the coupling capacitor used between two stages can be eliminated by using direct-coupled amplifiers. In the case of a vacuum-tube amplifier, the sole purpose of the coupling capacitor between the two stages is to keep the positive voltage applied to the plate of the tube off the grid of the following tube. We do this so the grid can be operated at dc ground potential and the cathode at a small positive voltage. In this way bias can be obtained for the tube. However, there is no reason why we cannot let the grid operate at a fairly high positive potential and simply operate the cathode at a still higher positive voltage. This will mean that the cathode will be positive with respect to the grid, or in other words, the grid will be negative with respect to the cathode.

A circuit where this is done is shown in Fig. 26. This type of amplifier is called a direct-coupled amplifier. Notice that there is no coupling capacitor used between V_1 and V_2. The circuit of V_1 is more or less conventional, but the circuit of V_2 is somewhat different from the amplifiers you have seen previously. Notice that the grid of V_2 is connected directly to the plate of V_1. It is obvious that with this type of connection we don't have to worry about an increase in coupling capacitor reactance at low frequencies, because there is no coupling capacitor. However, the plate of V_1 must have a positive voltage applied to it, and

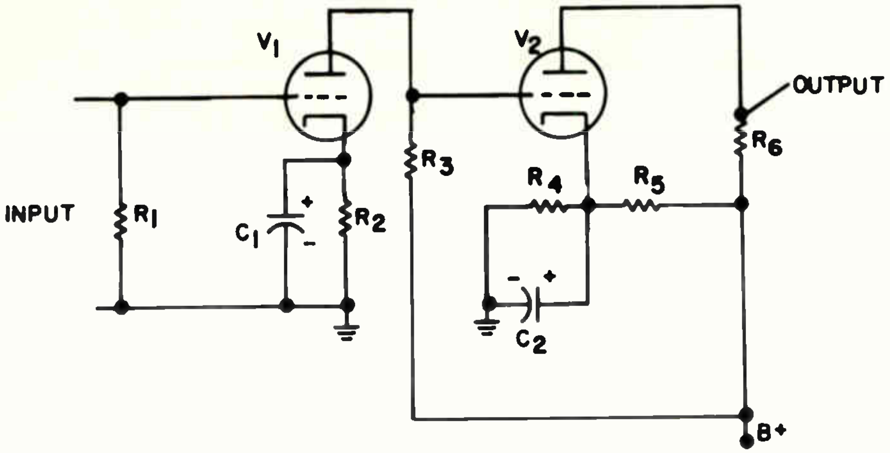


Fig. 26. A direct-coupled vacuum-tube amplifier.

therefore the grid of V_2 will have a positive voltage applied to it. By means of a voltage divider consisting of R_4 and R_5, we have obtained a positive voltage for the cathode of V_2, which is slightly higher than the positive voltage applied to the grid of V_2. C_2 keeps the cathode of V_2 at signal ground potential. Thus we have the signal applied directly between the cathode and grid of V_2. C_2 can be made very large so its reactance is negligible even at very low frequencies. Even if its reactance does start to rise, the value of R_4 is usually somewhat higher than the cathode resistor of a conventional R-C coupled stage. Thus the capacitor does not have to bypass such a low value resistor and more effective bypassing can be obtained.

One disadvantage of this type of amplifier is that aging of one tube appreciably affects the operation of the other. For example, if the emission of V_1 drops, the plate current drawn by this tube will drop. This means that the voltage drop across R_3 will decrease, and therefore the plate voltage on V_1 will increase. This increase in voltage might be enough to swing the grid of V_2 positive with respect to the cathode. Needless to say, when this happens, V_2 starts drawing a higher than normal current. Fortunately, when the tube starts drawing a higher than normal current, the voltage drop across R_4 increases and this tends to compensate for the increase in grid voltage to some extent. In some direct-coupled amplifiers you will find that the plate-load resistor R_3 is returned to a lower voltage than the plate-load resistor R_6. This makes it possible to use a lower value resistor for R_3 and thus tends to give better high-frequency response. You will remember that one of the first steps we did in order to get good high-frequency response from an amplifier was reduce the value of the plate-load resistor. This doesn't actually bring up the response but it does reduce the middle and lower frequencies so that we get a constant gain over a wider frequency range.

TRANSISTOR DIRECT-COUPLED AMPLIFIERS

Transistors lend themselves very well to direct coupling. An example of several transistors used in a direct-coupled circuit

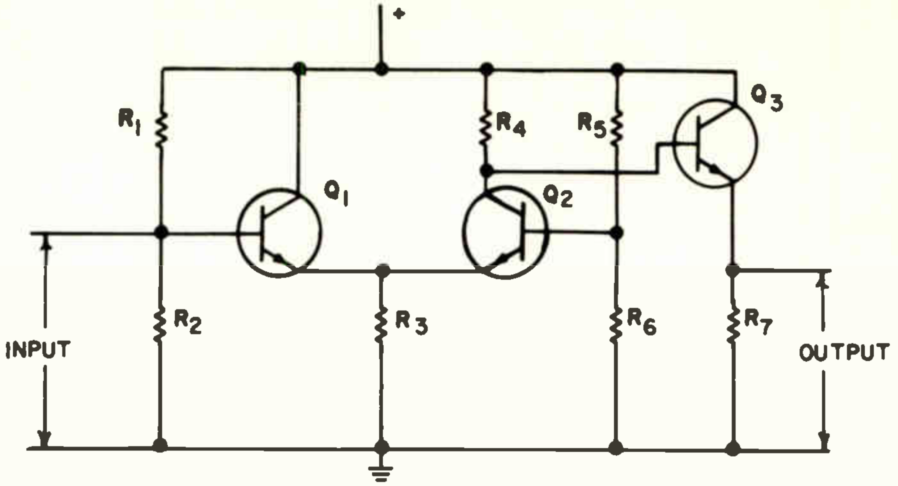


Fig. 27. Transistor direct-coupled stages.

is shown in Fig. 27. The resistors R_1 and R_2 provide a forward bias across the emitter-base junction of the NPN transistor Q_1. Forward bias across the emitter-base junction of Q_2 is provided by R_5 and R_6.

To see how the amplifier works, let's consider what happens when an input signal is applied between the base of Q_1 and ground. When the signal swings the base of Q_1 in a positive direction, current through Q_1 will increase. This causes the voltage drop across R_3 to increase. The increased voltage drop across R_3 increases the emitter voltage on Q_2 thus reducing the forward bias across the emitter-base junction of Q_2. Hence the current through this transistor goes down, and the voltage drop across R_4 will decrease. Therefore the collector of Q_2 will swing in a positive direction.

The collector of Q_2 is connected directly to the base of Q_3 which is used in an emitter-follower circuit. The dc voltage developed across R_7 is relatively low, so the output can be fed directly to the base of another amplifier configuration like Q_1 and Q_2. Of course, the varying signal fed to the base of Q_3 will cause the voltage across R_7 to vary.

The combination of transistors Q_1 and Q_2 is called a differential amplifier. This type of amplifier is widely used in integrated circuits that are used in some television receivers. The purpose of using the emitter follower after Q_2 is to reduce the dc voltage level. If we simply fed the base of a second differential amplifier pair from the collector of Q_2, the base of the following transistor would be at a higher potential than the base of Q_1. Thus for each two-stage differential amplifier we went through, the voltage would be gradually increasing. However, by using an emitter follower, the dc voltage across the emitter-resistor R_7 is quite low so that we can get back down to a low base voltage such as we had on Q_1 originally. By using a two-stage differential amplifier followed it by an emitter follower we can cascade groups of these stages any number of times to get the gain we need, while the operating voltage requirements are quite low.

PRINTED CIRCUIT BOARDS

One of the most common problems encountered in the early days of television, and when manufacturers first began to build wide-band amplifiers for other uses, was getting consistent results. In building a wide-band amplifier, stray capacities have an appreciable effect on the high-frequency response of the amplifier. One amplifier might have good frequency response up to 5 MHz and the next one built by the manufacturer, with the same parts and tubes, might have as good a response to only 4 MHz (or less). Often this is due simply to parts being put in slightly different positions and wires that were routed slightly different by the person who assembled the equipment.

Problems of this type have been almost completely eliminated by the use of printed circuit boards in the assembly of wide-band amplifiers. In the printed circuit board the wiring is actually on a phenolic or glass epoxy-type base. The wiring consists of copper strips that are glued to the base.

In manufacturing a printed circuit board the manufacturer starts off with a board that may have been made out of a phenolic material that is 1/16th of an inch thick. This material has a thin sheet of copper firmly glued to one side. The basic boards are available in sheets that are 4′ wide by 8′ long. The manufacturer cuts the desired size board from sheets of this type. In manufacturing the board for use in wide-band amplifiers, the wiring on the board is etched. To do this we simply draw the circuit and then transfer it photographically to the copper circuit board. The board is then placed in an etching solution and the undesired copper is etched away leaving only the copper desired to make the connections between the various parts on the board. The parts needed are then mounted on the other side of the board and connected to the copper wiring by inserting the part leads through holes that have been drilled or punched in the board. The leads to the various parts are then soldered to the copper wiring.

The advantage of an etched circuit board, of course, is that all parts fall into exactly the same place, the wiring falls in exactly the same place and hence distributed and stray capacities remain essentially constant from one board to the next. Thus assuming we hold the parts tolerances to a reasonable value, we can expect the frequency-response and gain of one amplifier to be essentially the same as the next one we manufacture.

In Fig. 28 we have shown a photograph of the circuit board containing the video amplifier of the Conar Model 600 Color Television Receiver. Notice that the tubes and parts are all mounted on one side of the circuit board and the wiring which interconnects all these components is in the form of copper on the other side of the board. The use of the printed circuit board ensures that video amplifiers of the various sets will have essentially the same frequency response.

One of the disadvantages of circuit boards is that they sometimes develop cracks. This may be due to rough handling of the equipment in which they are used. Sometimes the crack is so thin that you can't see it; sometimes we refer to this as a hairline crack. The crack in the circuitry may cause the equipment to perform intermittently.

Hairline cracks are quite difficult to locate, but they usually can be located by putting a little pressure on the board in various spots. You can do this with some

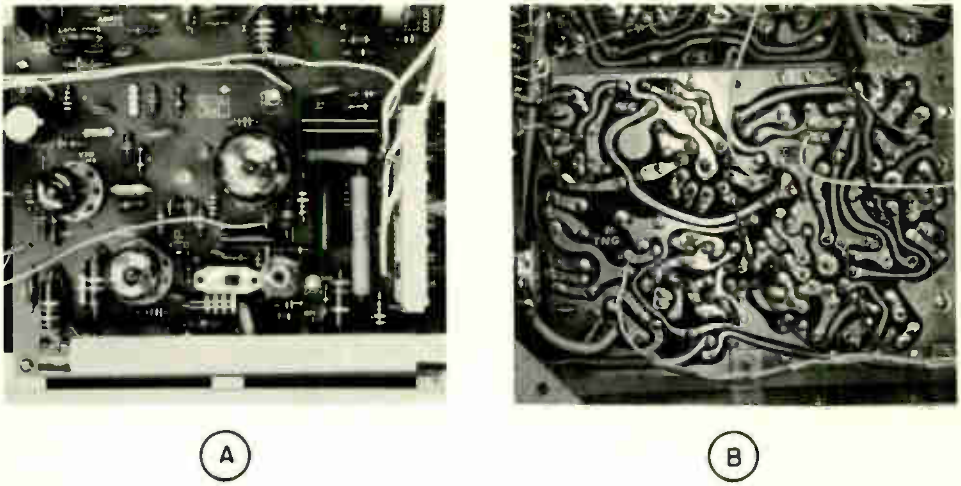


Fig. 28. Video amplifier on an etched circuit board. This type of wiring is referred to as printed wiring.

insulated tool; you will find that as you push in a certain spot the intermittent can be made to occur. Look for a hairline break in the copper wiring somewhere near this point. If you cannot find it, simply flow solder over the copper conductors in the area where you think the break is located and then try flexing the board again and see if the trouble is eliminated. The solder will usually bridge right across the crack and eliminate the intermittent.

Sometimes in repairing equipment in which a printed circuit board is used you'll accidentally pull the copper loose from the board. The copper is only glued to the board and can be easily knocked off by applying too much heat when you are replacing a part. In this case, you can effect a repair simply by taking a piece of wire and soldering the wire in place to complete the circuit between the two points from which the copper has been accidentally removed. Use a short direct piece of wire so you do not upset the performance of the board.

Printed circuit boards have added much insofar as obtaining consistent performance from wide-band amplifiers is concerned. They are not particularly difficult to work on as long as you make repairs quickly and avoid applying excessive heat or force to the board. Some servicemen do not like to work on printed circuit boards because it is somewhat more difficult to trace out the circuit than with the older style of hand wiring, but with a little practice you can learn to do this. Since most modern radio and TV receivers use printed circuitry it is important that you learn to work with this type of equipment.

SELF-TEST QUESTIONS

(z) What system is frequently used in transistor amplifiers to improve the overall frequency response of the amplifier?

(aa) How can you repair a "hairline" crack in a printed circuit board?

(ab) How can you repair a printed circuit board in which a piece of the copper has been accidentally removed?

(ac) What is the advantage of using an emitter follower after a differential amplifier such as shown in Fig. 27?

(ad) In the direct-coupled amplifier shown in Fig. 26, how is the high positive voltage on the grid of V_2 overcome?

(ae) What type of high-frequency compensation is used in the circuit shown in Fig. 23?

(af) What components form the low-frequency compensating network in the amplifier shown in Fig. 22?

LOOKING AHEAD

You can look forward to servicing many amplifiers in your career as an electronics technician. You will find amplifiers used in all types of electronic equipment. Wide-band amplifiers will be found in many different applications. Make sure that you understand wide-band amplifiers before leaving this lesson and going on to the next. A small amount of additional time spent on this lesson may save you a great deal of time later when you start working on equipment of this type.

Answers to Self-Test Questions

(a) A common logarithm is a number which tells us the power to which 10 must be raised in order to equal a given number.

(b) The characteristic.

(c) The mantissa.

(d) Two. The characteristic will be one less than the number of digits in the number. Since all numbers between 100 and 999 have three digits, the characteristic will be 2.

(e) The logarithm of 7 is .8451. The characteristic is 0, so it is simply omitted.

(f) The logarithm of 700 is 2.8451. The mantissa is the same as for the logarithm of 7 or for the logarithm of 70 for that matter. The characteristic, which is 2, indicates that the number is somewhere between 100 and 999.

(g) The logarithm of 41.7 is 1.6201. We find this logarithm by locating 41 in the N column of the log table and then moving over to the column under 7 where we see that the mantissa is .6201. 41 has two digits in it so we know that the characteristic must be 1 and therefore the complete logarithm is 1.6201.

(h) The bel is a power ratio. It is equal to the logarithm of the ratio of one power to another power.

(i) The decibel is one tenth of a bel. A decibel is a power ratio and it is equal to ten times the logarithm of one power divided by another. It is expressed by the formula:

$$\text{db} = 10 \log \frac{P_1}{P_2}$$

(j) 7.782 db. To find the change in db we let P_1 equal 222 watts and P_2 equal 37 watts. Now we substitute these values in the decibel power formula and we get:

$$\text{db} = 10 \log \frac{222}{37}$$

dividing 37 into 222 gives us 6 so the change in db equals

$$\text{db} = 10 \log 6 = 10 \times .7782 = 7.782$$

(k) 6 db. To find the answer we use the voltage formula:

$$\text{db} = 20 \log \frac{E_1}{E_2}$$

and we substitute 150 volts for E_1 and 75 volts for E_2 so that we have:

$$\begin{aligned} \text{db} &= 20 \log \frac{150}{75} \\ &= 20 \log 2 \\ &= 20 \times .301 \\ &= 6.0 \text{ db} \end{aligned}$$

(l) To increase the frequency at which the reactance of the shunt capacities becomes equal to the resistance of the plate-load resistor.

(m) If we use too large a grid resistor in a vacuum-tube amplifier, electrons accidentally striking the grid and flowing through the resistor may build up an appreciable bias in the grid of the tube. Another possibility is that the tube may have a small amount of gas. The gas molecules striking the grid will cause a current to flow through the grid resistor that will place a positive bias on the grid of the tube. If we use too large a grid resistor this positive bias may be high enough to cause an excessive current to flow through the tube and destroy the tube.

(n) At high frequencies L_1 resonates with the capacity in the circuit and hence tends to increase the value of the plate load of V_1. Thus the effect of the shunting capacity is reduced.

(o) L_1 is a series-peaking coil. It separates the shunt capacity in the output of V_1 from the shunt capacity in the input of V_2. It forms a series-resonant circuit with the capacity in the input of V_2 and hence builds up the voltage applied to the grid of V_2 at high frequencies.

(p) By series-shunt peaking we mean a combination of shunt peaking such as shown in Fig. 5 and series peaking such as shown in Fig. 8. A series-shunt compensated amplifier is shown in Fig. 10.

(q) No. The low output resistance of the first stage along with the low input resistance of the second stage reduces the effective value of the collector-load resistor in the first amplifier stage. Therefore it takes a larger shunt capacity to produce a capacitive reactance equal to the resistance of the emitter load. As a result, the response of a transistor amplifier frequently starts to fall off at a somewhat higher frequency than the response of a vacuum-tube amplitier.

(r) Yes, the time that it takes the electrons to cross the base of a transistor may become equal to the period of one half cycle at some high frequency. When this happens, instead of getting a 180° phase shift in the common-emitter transistor circuit, we get a 360° phase shift so that the signal in the emitter circuit will be in-phase with the signal in the base circuit. This will cause positive feedback through the transistor and cause the transistor to go into self oscillation.

(s) More like those encountered in vacuum tubes. Because of the high input and output resistances of the field-effect transistor, the field-effect transistor resembles a vacuum tube more closely in performance than it does a transistor. Thus series and shunt peaking are quite effective in improving the high-frequency response of an amplifier using field-effect transistors.

(t) The reactance of the coupling capacitor used between the two stages becomes too high.

(u) Phase shift.

(v) Low-frequency compensation. This usually consists of adding a resistance and a capacitance in the output circuit of the first stage. By selecting the correct value of resistance and capacitance, both the gain and the phase shift can be improved.

(w) No, it is more effective in vacuum-tube circuits, but can be used to some extent in transistor circuits.

(x) Yes. Field-effect transistors have characteristics similar to vacuum tubes and low-frequency compensation is equally effective in the two.

(y) By cathode degeneration we are referring to the reactance of the cathode bypass capacitor becoming so high that the capacitor is no longer an effective bypass. This occurs at very low frequencies and causes poor low-frequency response. It can be overcome by omitting the cathode bypass capacitor so that the degeneration becomes constant at all frequencies. This levels off the gain of the amplifier.

(z) Negative feedback. In a two-stage amplifier, a signal is taken from the second stage and fed back to the first stage to detract from the original signal applied to the first stage. Thus if the output signal of an amplifier tends to increase, the feedback increases reducing the overall gain of the amplifier. On the other hand, if the output tends to fall off, the feedback signal decreases, allowing the amplifier gain to increase.

(aa) By applying a small amount of pressure to the circuit board you can frequently isolate the area in which the crack exists. Then by flowing solder over the copper in that area you can frequently bridge the gap.

(ab) You can bridge the copper by means of a piece of hookup wire. The two ends of the hookup wire are simply soldered in place so that the wire takes the place of the copper that has been accidentally removed.

(ac) It reduces the dc voltage level in the circuit so that the next differential amplifier pair can be operated at the same dc potential as the first. This keeps the power supply requirements quite modest.

(ad) The bias network consisting of R_4 and R_5 places the cathode of V_2 at a higher positive potential than the grid. Thus even though the grid is positive with respect to ground, it is still negative with respect to the cathode.

(ae) Both series and shunt peaking are used.

(af) R_6 and C_4.

Lesson Questions

Be sure to number your Answer Sheet B204.

Place your Student Number on every Answer Sheet.

Most students want to know their grade as soon as possible so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time, or you may run out of lessons before new ones can reach you.

1. What is the logarithm of 2000?

2. Suppose the power output from power amplifier A is increased from 100 to 200 watts, and the power output from power amplifier B is increased from 1 to 5 watts. Which change is the larger change in decibels?

3. Why can the coupling capacitor used between two resistance-capacitance coupled stages be ignored at the middle and high frequencies?

4. What limits the high-frequency response of an R-C coupled amplifier?

5. What effect does reducing the size of the plate load resistor in an amplifier to extend the high-frequency response have on the gain at the middle and low frequencies?

6. Name the two types of peaking used to extend the high-frequency response of an amplifier.

7. Why can we not increase the size of the base resistor R_4 in a transistor amplifier such as shown in Fig. 16B to improve the low-frequency response of the two stage amplifier?

8. Why is an electrolytic capacitor used as a cathode bypass or an emitter bypass sometimes shunted by a paper or a ceramic capacitor?

9. What method can be used other than peaking coils and low-frequency compensation to improve the frequency response of an amplifier?

10. In the direct coupled transistor amplifier circuit shown in Fig. 27, what primary purpose does Q_3 serve?

REVERE OUR LAWS

Let every American, every lover of liberty, every well-wisher to his posterity swear by the blood of the Revolution never to violate in the least particular the laws of the country - Let every man remember that to violate the laws is to trample on the blood of his father, and to tear the charter of his own and his children's liberty.

Let reverence for the laws be breathed by every American mother to the lisping babe that prattles on her lap; let it be taught in schools, in seminaries, and in colleges; let it be written in primers, spelling books and in almanacs; let it be preached from the pulpit, proclaimed in legislative halls and enforced in courts of justice. And in short, let it become the political religion of the nation; and let the old and the young, the rich and the poor, the grave and the gay of all sexes and tongues and colors and conditions, sacrifice unceasingly upon its altars.

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RADIO RULES AND REGULATIONS

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RADIO RULES AND REGULATIONS

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STUDY SCHEDULE

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RADIO RULES AND REGULATIONS

All forms of rf radiation are subject to the control of the Federal Communications Commission (FCC). Control of rf radiation is necessary in order to keep radio transmissions from interfering with one another, and in order to insure that the various groups that use rf energy will have sufficient frequencies available to them to carry on their functions.

For instance, the military must have special frequencies reserved so that it can carry out vital communications and other functions. In order to make sure that these frequencies are not interfered with, all those who use rf energy are licensed, and also, the various types of equipment they use are assigned frequencies that will not interfere with other essential services. The different uses that are made of rf energy are referred to as "services." Thus, we have "Amateur Service," Television Service, "FM Service," and so on.

The usual procedure is to license both the station and the operator. The licensing regulations for equipment are designed to insure that the equipment will do the job for which it is designed without interfering with other services. The licensing of operators helps make sure that the users of radio transmitters are familiar with the regulations relating to their use, and that they will be able to use them properly for their intended purpose.

The object of this book is to tell you where you can find the information that is necessary to obtain these licenses and what the licenses permit you to do. Most of this information is contained in the Rules and Regulations issued by the FCC. Your main problem in dealing with these extensive regulations will be to find what you want to know in them. This book will give you a good idea of where to look.

ORGANIZATION OF THE RULES AND REGULATIONS OF THE FCC

The various topics covered by the rules and regulations of the FCC are issued in separate parts. These parts have been gathered together in ten (10) separate volumes for publication. The contents of these ten volumes are as follows:

Volume 1

Part 0 -- Commission Organization.
Part 1 -- Practice and Procedure.
Part 13 -- Commercial Radio Operators.
Part 17 -- Construction, Marking, and Lighting of Antenna Structures.
Part 19 -- Employee Responsibilities and Conduct.

Volume 2

Part 2 -- Frequency Allocations and Radio Treaty Matters; General Rules and Regulations.
Part 5 -- Experimental Radio Services (other than Broadcast).
Part 15 -- Radio Frequency Devices.
Part 18 -- Industrial, Scientific, and Medical Equipment.

Volume 3

Part 73 -- Radio Broadcast Services.
Part 74 -- Experimental, Auxiliary, and Other Program Distributional Services.

Volume 4

Part 81 -- Stations on Land in the Maritime Services.
Part 83 – Stations on Shipboard in the Maritime Services.
Part 85 -- Public Fixed Stations and Stations of the Maritime Services in Alaska.

Volume 5

Part 87 -- Aviation Services.
Part 89 -- Public Safety Radio Services.
Part 91 -- Industrial Radio Services.
Part 93 -- Land Transportation Radio Services.

Volume 6

Part 95 -- Citizens Radio Service.
Part 97 -- Amateur Radio Service.
Part 99 -- Disaster Communications Service.

Volume 7

Part 21 – Domestic Public Radio Services (other than Maritime Mobile).
Part 23 -- International Fixed Public Radiocommunication Services.
Part 25 – Satellite Communications.

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Part 31 -- Uniform System of Accounts for Class A and Class B Telephone Companies.
Part 33 -- Uniform System of Accounts for Class C Telephone Companies.

Volume 9

Part 34 – Uniform System of Accounts for Radiotelegraph Carriers.
Part 35 - Uniform System of Accounts for Wire-Telegraph and Ocean-Cable Carriers.

Volume 10

Part 41 -- Telegraph and Telephone Franks.
Part 42 -- Preservation of Records of Communication Common Carriers.
Part 43 -- Reports of Communication Common Carriers and Certain Affiliates.
Part 51 – Occupational Classification and Compensation of Employees of Telephone Companies.
Part 52 -- Classification of Wire-Telegraph Employees.
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Part 63 – Extension of Lines and Discontinuance of Service by Carriers.
Part 64 -- Miscellaneous Rules Relating to Common Carriers.
Part 66 -- Applications Relating to Consolidation, Acquisition, or Control of Telephone Companies.
Part 67 -- Jurisdictional Separations.

You can see that the first seven volumes contain the information you are most likely to need. In fact, you will usually find that the material is grouped in these volumes in such a way that you will not need to get all of the first seven volumes in order to cover a particular field. You should find it a good investment in both time and money to buy and study the Rules and Regulations that apply to the particular field you are working in.

Copies of these volumes are not on sale

by the FCC. To buy a copy, you should write to the Superintendent of Documents, Government Printing Office, Washington, D. C. 20402.

When you buy a copy of the regulations, the corrections for that volume are sent to you, as issued, as part of the price of the volume. This arrangement helps insure that the outstanding volumes will all be complete and up to date.

Licensing Requirements

As mentioned earlier, usually both the station and the operator of a transmitting radio station must be licensed. Since the main object of the licensing requirements is to make sure that radio transmissions are carefully controlled, there is no need for licensing radio receivers. In this section, we will discuss the requirements for both operator and station licenses. These licenses can be thought of as being of either one of two types: commercial or amateur.

COMMERCIAL OPERATOR LICENSES

Several different classes of operator licenses are issued to those who work in the commercial radio services. All but one of these licenses require the applicant to pass a written examination.

Examination Elements. The written examination for a particular class of commercial operator's license consists of one or more of the following parts, called Elements, that are described in Section 13.21 of the Rules of the FCC.

The elements are as follows:

1. **Basic Law. Provisions of laws, treaties and regulations with which every operator should be familiar.**
2. **Basic operating practice. Radio operating procedures and practices generally followed or required in communicating by means of radiotelephone stations.**
3. **Basic radiotelephone. Technical, legal and other matters applicable to the operation of radiotelephone stations other than broadcast.**
4. **Advanced radiotelephone. Advanced technical, legal and other matters particularly applicable to the operation of the various classes of broadcast stations.**
5. **Radiotelegraph operating practice. Radio operating procedures and practices generally followed or required in communicating by means of radiotelegraph stations primarily other than in the maritime mobile services of public correspondence.**
6. **Advanced radiotelegraph. Technical, legal and other matters applicable to the operation of all classes of radiotelegraph stations, including operating procedures and practices in the maritime mobile services of public correspondence, and associated matters such as radio-navigational aids, message traffic routing and accounting, etc.**
7. **Aircraft radiotelegraph. Basic theory and practice in the operation of radio communication and radio-navigational systems in general use on aircraft.**
8. **Ship radar techniques. Specialized theory and practice applicable to the proper installation, servicing and maintenance of ship radar equipment in general use for marine navigational purposes.**
9. **Basic Broadcast. Basic regulatory matters applicable to the operation of standard commercial FM, and noncommercial educational FM broadcast stations.**

Classes of Licenses. The different classes of operators' licenses, and the examinations they require are set forth in Section 13.22 as follows:

(a) Radiotelephone Second Class Operator License:

1. **Ability to transmit and receive spoken messages in English.**
2. **Written examination elements: 1, 2, and 3.**

(b) Radiotelephone First Class Operator License:

1. **Ability to transmit and receive spoken messages in English.**
2. **Written examination elements: 1, 2, 3, and 4.**

(c) Radiotelegraph Second Class Operator License:

1. Ability to transmit and receive spoken messages in English.
2. Transmitting and receiving code test of twenty (20) words per minute plain language and sixteen (16) code groups per minute.
3. Written examination elements: 1, 2, 5, and 6.

(d) Temporary limited radiotelegraph Second Class Operator License:

1. Ability to transmit and receive spoken messages in English.
2. Transmitting and receiving code test of twenty (20) words per minute plain language and sixteen (16) code groups per minute.

(e) Radiotelegraph First Class Operator License:

1. Ability to transmit and receive spoken messages in English.
2. Transmitting and receiving code test of twenty-five (25) words per minute plain language and twenty (20) code groups per minute.
3. Written examination elements: 1, 2, 5, and 6.

(f) Radiotelephone Third Class Operator Permit:

1. Ability to transmit and receive spoken messages in English.
2. Written examination elements: 1 and 2.

(g) Radiotelegraph Third Class Operator Permit:

1. Ability to transmit and receive spoken messages in English.
2. Transmitting and receiving code test of twenty (20) words per minute plain language and sixteen (16) code groups per minute.
3. Written examination elements: 1, 2, and 5.

(h) Restricted Radiotelephone Operator Permit:

No oral or written examination is required for this permit. In lieu thereof, applicants will be required to certify in writing to a declaration which states that the applicant has need for the requested permit; can receive and transmit spoken messages in English; can keep at least a rough written log in English or in some other language in general use that can be readily translated into English; is familiar with the provisions of treaties, laws, and rules and regulations governing the authority granted under the requested permit; and understands that it is his responsibility to keep currently familiar with all such provisions.

Section 13.45 provides that in computing the number of code groups in a code test, "Each five characters shall be counted as one word or code group. Punctuation marks or figures count as two characters."

Additional requirements also apply to applicants for Radiotelegraph First Class Operator Licenses. They must be at least 21 years old at the time the license is issued, and have at least 1 year's service as a radiotelegraph operator.

Examination Procedures. All written examinations must be handwritten in ink, but diagrams may be in pencil. It takes a grade of 75% to pass. Each element must be passed separately, and an applicant who fails any element may not be re-examined on that element for a period of 2 months. However, if you pass some elements and fail others, you do not need to be re-examined except on the elements you fail. Also, if you hold one class of license, and wish to qualify for another class, you need to pass only the additional elements that are contained in the requirements for the new licenses.

Your NRI course contains nearly all of the technical information that you will need in order to answer the questions on the FCC examinations. However, it is frequently helpful to use an examination study guide, which is put out by the FCC. This study guide has the information covered by the elements of the examination organized into the general headings covered. You can buy a copy of this study guide, which is called, "Study Guide and Reference Material for Commercial Radio Operator Examinations," from the Superintendent of Documents, Government Printing Office, Washington, D. C. 20402.

A restricted radiotelephone operator's permit is usually issued for life, but other commercial operator's licenses run for 5 years. Most other licenses may be renewed within the last year of their term if the holder has completed sufficient service as a radio operator using the license. This arrangement makes it unnecessary for full-time operators who are actively engaged in communications to be reexamined every five years. In fact, first- and second-class licenses can often be renewed even without the service requirement.

You can see that the qualifications for an operator's license cover much more than simply the ability to operate radio equipment. Much of the licensing requirements have to do with the ability to understand the operation of rf transmitters well enough to be able to service them. For instance, in order to be permitted to service marine radar equipment, the holder of the first- or second-class operator's license must also pass a written examination on Element 8, and have his license specially endorsed to show that he is qualified to service this type of equipment.

Place of Examination. Operator examinations are held at the district offices and sub-offices of the Federal Communications Commission. These offices are located in cities all over the country. Table I shows the location of the various offices. The time of the examinations is not the same at the various offices. Therefore, if you wish to take an examination at an office near your home, write to the Engineer in Charge at that office to find out when the examination of the type you are interested in is to be given.

COMMERCIAL STATION LICENSES

Obtaining a station license for an AM, FM, or TV broadcast station is a long drawn-out affair. The procedure is set up to enable the applicants to *"satisfy the Commission that they are legally, technically, and financially qualified, and that operation of the proposed station would be in the public interest."*

Part 1 of the Commission's Rules contains the steps of the licensing procedure, and Part 73 contains the technical standards the station must be able to meet, and much other information that is needed in applying for a license.

For instance, the TV channel assignments by states and communities are contained in Part 73, so you can tell by referring to this part what channels are assigned to your community.

One of the first things you must do in applying for a broadcast AM, FM, or TV license is to determine what frequencies, if any, are available for assignment to your particular area. This may be much more difficult than it sounds. Frequently it requires the services of a competent engineer. Another step in the procedure, which can be highly technical, is the selection of a proper site for the transmitter.

Construction Permits. The first formal step in dealing with the Commission comes when applying for a construction permit. This application is made on a form that calls for information about the citizenship and character of the applicant, his financial, technical and other qualifications, as well as details about the transmitting equipment to be used, an-

DIST. NO.	LOCATION	DIST. NO.	LOCATION
1	1600 Customhouse India and State Streets Boston, Massachusetts 02109	11	U. S. Courthouse 312 N. Spring St. Los Angeles, California 90012
2	748 Federal Building 641 Washington Street New York, New York 10014	12	323A Courthouse 555 Battery Street San Francisco, California 94111
3	1005 New U. S. Customhouse 2nd & Chestnut Streets Philadelphia, Pennsylvania 19106	13	314 Multnomah Bldg. 319 S. W. Pine Street Portland, Oregon 97204
4	819 Federal Bldg. 31 Hopkins Plaza Baltimore, Maryland 21201	14	8012 Federal Office Building 909 First Avenue Seattle, Washington 98104
5	Military Circle 870 North Military Hwy. Norfolk, Virginia 23502	15	504 New Customhouse 19th St. bet. Calif. & Stout Sts. Denver, Colorado 80202
6	1602 Gas Light Tower 235 Peachtree St., N. E. Atlanta, Georgia 30303	16	691 Federal Building 4th and Robert Streets St. Paul, Minnesota 55101
7	919 Federal Building 51 S. W. First Avenue Miami, Florida 33130	17	1703 Federal Building 601 East 12th Street Kansas City, Missouri 64106
8	829 Federal Building South 600 South Street New Orleans, Louisiana 70130	18	1872 U. S. Courthouse 219 South Dearborn Street Chicago, Illinois 60604
9	5636 Federal Building 515 Rusk Avenue Houston, Texas 77002	19	1054 Federal Building Washington Blvd. & LaFayette St. Detroit, Michigan 48226
10	707 Thomas Building 1314 Wood Street Dallas, Texas 75202	20	328 Federal Office Building 121 Ellicott Street Buffalo, New york 14203

Table I. Mailing addresses for field engineering offices of the FCC are listed here and on the back of this page.

DIST. NO.	LOCATION	DIST. NO.	LOCATION
21	502 Federal Building P. O. Box 1021 Honolulu, Hawaii 96808	23	54 U. S. Post Office Building 4th Ave. between F & G Sts. Anchorage, Alaska 99501
22	322 Federal Building P. O. Box 2987 San Juan, Puerto Rico 00903	24	Room 216 1919 M. Street, N. W. Washington, D. C. 20554

SUB-OFFICES

DIST. NO.	LOCATION	DIST. NO.	LOCATION
6S	238 Post Office Building York & Bull Streets Savannah, Georgia 31402	9B	239 Federal Building 300 Willow Street Beaumont, Texas 77701
7T	738 Federal Building 500 Zack Street Tampa, Florida 33602	11SD	Fox Theatre Building 1245 Seventh Avenue San Diego, California 92101
8M	439 U. S. Courthouse 113 St. Joseph St. Mobile, Alabama 36602	11SP	300 South Ferry Terminal Island San Pedro, California 90731

SAMPLE ADDRESS

Engineer in Charge, FCC
238 Post Office Building
York & Bull Streets
Savannah, Georgia 31402

tenna and studio locations, and the type of broadcasting to be undertaken. Information must also be supplied that will show what interference problems, if any, will be caused by the proposed station, and how and to what extent these problems are to be solved.

The procedures followed in processing the construction permit application include provisions for hearings, if necessary, for protesting of the granting of the permit by other interested parties, and for appealing any ruling.

Sometimes, of course, more than one applicant will be trying to obtain a license for a station in a given area. Also, other stations on the same frequency in different areas may protest the granting of a permit if they feel that there is a possibility of interference from the new station. Such parties would be possible sources of objection to the granting of a construction permit.

Once a construction permit is granted, the construction of the station must begin promptly, and finish within a specified time fixed by the Commission. After the station is completed, the builder conducts equipment tests, submits the station to an inspection by the Engineer in Charge of the radio district in which he is located, and applies to the Commission for a license.

The application for a license must *"show compliance with the terms and conditions of the construction permit."* When the license application is made, the usual procedure is to request authority for *"program tests."* This authority permits the applicant to commence broadcast operations while his application for a license is being processed. Of course, broadcasting cannot be started until the authority for *"program tests"* is actually given by the Commission.

Type-Accepted and Type-Approved Lists. You can see from even this brief description that licensing a radio transmitting station can be quite complicated.

For some services, matters are simplified considerably by the use of equipment on lists put out by the FCC called *"type-accepted"* and *"type-approved"* lists. "Type-approved" means that the engineers of the FCC have tested a model of the equipment to make sure it will perform properly. "Type-accepted" means that the equipment has been checked out by private engineers employed by the manufacturer, who then submit a request for type acceptance to the FCC. Either kind of approval by FCC has the same effect.

These lists are kept at each field office of the FCC, and by the manufacturers of the type-accepted and type-approved equipment. Selecting equipment from these lists greatly simplifies the problem of satisfying the requirements for a suitable transmitter. This is another of several technical problems to be solved in obtaining a broadcast station license.

AMATEUR OPERATOR LICENSES

Obtaining an amateur operator's license is covered in Volume VI of the Rules and Regulations. Let's look at some of the requirements.

Examination Elements. Examinations for amateur operator's licenses are also broken down into elements. These elements are set forth in Section 97.21 of the Rules as follows:

Examinations for amateur operator privileges will comprise one or more of the following examination elements.

(a) Element 1(A): Beginner's code test at five (5) words per minute;(b) Element 1(B):

General code test at thirteen (13) words per minute;

(c) Element 1(C): Expert's code test at twenty (20) words per minute;

(d) Element 2: Basic law comprising rules and regulations essential to beginners' operation, including sufficient elementary radio theory for the understanding of those rules;

(e) Element 3: General amateur practice and regulations involving radio operation and apparatus and provisions of treaties, statutes, and rules affecting amateur stations and operators;

(f) Element 4(A): Intermediate amateur practice involving intermediate level radio theory and operation as applicable to modern amateur techniques, including, but not limited to, radiotelephony and radiotelegraphy;

(g) Element 4(B); Advanced amateur practice involving advanced radio theory and operation as applicable to modern amateur techniques, including, but not limited to, radiotelephony, radiotelegraphy, and transmissions of energy for measurements and observations applied to propagation, for the radio control of remote objects and for similar experimental purposes.

Classes of Licenses. Sections 97.9 and 97.23 set out the examination requirements for the various classes of licenses.

All applicants must be U. S. citizens. There is no age restriction.

Applicants for original licenses will be required to pass the following examination elements:

(a) Amateur Extra Class: Elements 1(C), 3, 4(A), and 4(B);

(b) Advanced Class: Elements 1(B), 3, and 4(A);

(c) General Class and Conditional Class: Elements 1(B) and 3;

(d) Technician Class: Elements 1 (A) and 3.

(e) Novice Class: Elements 1(A) and 2.

In addition, applicants for Amateur Extra Class licenses must have held an amateur license other than a Novice or Technician for a period of two years.

Examination Procedures. Section 97.29 describes the manner of conducting examinations:

(a) The examination for Amateur Extra, Advanced, and General Classes of amateur operator licenses will be conducted by an authorized Commission employee or representative at locations and at times specified by the Commission.

(b) Unless otherwise prescribed by the Commission, an examination for the Conditional, Technician, or Novice Class license will be conducted and supervised by a volunteer examiner selected by the applicant. A volunteer examiner shall be at least 21 years of age and shall be the holder of an Extra, Advanced, or General Class Amateur Radio operator license, or shall hold a Commercial radiotelegraph operator license issued by the Commission, or shall be employed in the service of the United States as the operator of a manually operated radiotelegraph station.

The section continues with details about supervision, written portion of the examination, and administration of examinations by the Commission.

Section 97.27 states that: The examinations for Conditional Class will be available only under one or more of the following conditions:

(a) If the applicant's actual residence and proposed amateur station location are more than 175 miles airline distance from the nearest location at which examinations are conducted by an authorized Commission employee or representative at intervals of not more than 6 months for amateur operator license.

(b) If the applicant is shown by physician's certificate to be unable to appear for examination because of protracted disability.

(c) If the applicant is shown by certificate of the commanding officer to be in the armed forces of the United States at an Army, Navy, Air Force, or Coast Guard Station and, for that reason, to be unable to appear for examination at the time and place designated by the Commission.

(d) If the applicant demonstrates by sufficient evidence that his temporary residence is for a continuous period of at least 12 months outside the continental limits of the United States, its territories or possessions, irrespective of other provisions of this section.

Code Tests. Section 97.29 describes the Code Test Procedure:

The code test required of an applicant for an amateur radio operator license, in accordance with the provisions of §§97.21 and 97.23 shall determine the applicant's ability to transmit by hand key (straight key or, if supplied by the applicant, any other type of hand-operated key such as a semi-automatic or electronic key), and to receive by ear, in plain language, messages in the International Morse Code at not less than the prescribed speed, free from omission or other error for a continuous period of at least 1 minute during a test period of 5 minutes counting five characters to the word, each numeral or punctuation mark counting as two characters.

Grading of Examinations. Passing the code test for a particular class of examination is a must. Section 97.31 provides:

(a) Code tests for sending and receiving are graded separately. Failure to pass the required code test for either sending or receiving will terminate the examination.

(b) Seventy-four percent (74%) is the passing grade for written examinations. For the purpose of grading, each element required in qualifying for a particular license will be considered as a separate examination. All written examinations will be graded only by Commission personnel.

Eligibility for Re-examination. Section 97.33 says:

An applicant who fails examination for an amateur operator license may not take another examination for the same or a higher class amateur operators license within 30 days, except that this limitation shall not apply to an examination for an Advanced or General Class license following an examination conducted by a volunteer examiner for a Novice, Technician, or Conditional Class license.

Volunteer Examiners. Some of the examinations are not conducted by Commission employees, but by volunteer examiners. Holders of licenses obtained under a volunteer examiner may be required to submit to an examination conducted by an employee of the Commission, as set forth in Section 97.35.

The Commission may require a licensee holding a Novice, Technician, or Conditional Class of operator license to appear for a Commission-supervised license examination at a location designated by the Commission. If the licensee fails to appear for this examination when directed to do so, or fails to pass such examination, the Novice, Technician, or Conditional Class operator license previously issued shall be subject to cancellation, and upon cancellation, a new license will not be issued for the same class operator license as that cancelled.

A holder of a Conditional Class License, obtained on the basis of an examination under the provisions of 97.29(b), is not required to be re-examined when changing residence and station location to within regular examination area, nor when a new examination location is established within 175 miles airline distance from such licensee's residence and station location.

Another distinction that is made between amateur examinations conducted by a Commission employee and those that are not, is in the matter of examination credit. Provisions of Section 97.25 state that credit is not given toward a higher grade of license for elements that are passed during an examination conducted by a volunteer examiner:

(a) **An applicant for a higher class of amateur operator license who holds a valid amateur operator license issued upon the basis of an examination by the Commission will be required to pass only those elements of the higher class examination that were not included in the examination for the amateur license held when such application was filed. However, credit will not be allowed for licenses issued on the basis of an examination given under the provisions of § 97.29(b).**

(b) **An applicant for any class of amateur operator license, except the Extra Class, will be given credit for the telegraph code element if within five years prior to the receipt of his application by the Commission he held a commercial radiotelegraph operator license or permit issued by the Federal Communications Commission.**

(c) **An applicant for Amateur Extra Class operator license will be given credit for examination elements 1(C), 4(A), and 4(B) if he so requests and submits evidence of having held a valid amateur radio station or operator license issued by any agency of the U. S. Government during or prior to April 1917, and qualifies for or currently holds a valid amateur operator license of the General or Advanced Class.**

(d) **No examination credit, except as herein provided, shall be allowed on the basis of holding or having held any amateur or commercial operator license.**

AMATEUR STATION LICENSES

The granting of an amateur station license is much less complicated than the granting of a commercial station license. For instance, Section 97.37 provides:

> **A license for an amateur station will be issued in response to proper application therefor to a licensed amateur operator at a designated fixed location. An amateur station license may also be issued to an individual, not a licensed amateur operator (other than an alien or a representative of an alien or of a foreign government), who is in charge of a proposed amateur station for recreation under military auspices (only of the Armed Forces of the United States) which is to be located in approved public quarters but not operated by the United States Government.**

Location of Station. The license is not limited to one location or type of equipment. Section 97.43 sets forth the conditions for a more extensive installation along with those for a single location:

(a) **Every amateur station shall have a fixed transmitter location. Only one fixed transmitter location will be authorized and will be designated on the license for each amateur station, except that when remote control is authorized, the location of the remote control position as well as the location of the remotely controlled transmitter shall be considered as fixed transmitter locations and will be so designated on the station license. Unless remote control of the transmitting apparatus is authorized, such apparatus shall be operated only by a duly licensed amateur radio operator present at the location of such apparatus.**

(b) **Authority for operation of an amateur station with the licensed operator on duty at a specific remote control point in lieu of the remote transmitter location may be granted upon filing an application for an individual station license on FCC Form 610, or on FCC Form 610.B for an amateur club or military recreation station.**

NOTE: These conditions, six paragraphs (1) through (6) are not listed herein. The form should be obtained and the subsection studied when authorization by the Commission is desired.

(c) **An amateur transmitter may be operated from a remote control point in lieu of the remote transmitter location without special authorization by the Commission**

when there is direct mechanical control or direct control by wired connections of the transmitter from a point located in the same or closely adjoining building or structure provided there is full compliance with the conditions set forth in paragraphs (b) (1) through (6) of this section.

Antenna Systems. The antenna system that is used with an amateur transmitter must be within the limitations of the Rules and Regulations. Section 97.45 provides:

(a) Except as provided in paragraph (b) of this section, an antenna for a station in the Amateur Radio Service which exceeds the following height limitations may not be erected or used unless notice has been filed with both the FAA on FAA Form 7460-1 and with the Commission on Form 714 or on the license application form, and prior approval by the Commission has been obtained for:

(1) Any construction or alteration of more than 200 feet in height above ground level at its site (§17.7(a) of this chapter).

(2) Any construction or alteration of greater height than an imaginary surface extending outward and upward at one one of the following slopes (§17.7(b) of this chapter):

(i) 100 to 1 for a horizontal distance of 20,000 feet from the nearest point of the nearest runway of each airport with at least one runway more than 3,200 feet in length, excluding heliports and seaplane bases without specified boundaries, if that airport is either listed in the Airport Directory of the current Airman's Information Manual or is operated by a Federal military agency.

(ii) 50 to 1 for a horizontal distance of 10,000 feet from the nearest point of the nearest runway of each airport with its longest runway no more than 3,200 feet in length, excluding heliports and seaplane bases without specified boundaries, if that airport is either listed in the Airport Directory or is operated by a Federal military agency.

(iii) 25 to 1 for a horizontal distance of 5,000 feet from the nearest point of the nearest landing and takeoff area of each heliport listed in the Airport Directory or operated by a Federal military agency.

(3) Any construction or alteration on an airport listed in the Airport Directory of the Airman's Information Manual (§17.7(c) of this chapter).

(b) A notification to the Federal Aviation Administration is not required for any of the following construction or alteration:

(1) Any object that would be shielded by existing structures of a permanent and substantial character or by natural terrain or topographic features of equal or greater height, and would be located in the congested area of a city, town, or settlement where it is evident beyond all reasonable doubt that the structure so shielded will not adversely affect safety in air navigation. Applicants claiming such exemption shall submit a statement with their application to the Commission explaining the basis in detail for their finding (§17.14(a) of this chapter).

(2) Any antenna structure of 20 feet or less in height except one that would increase the height of another antenna structure (§17.14(b) of this chapter).

(c) Further details as to whether an aeronautical study and/or obstruction marking and lighting may be required, and specifications for obstruction marking and lighting when required, may be obtained from Part 17 of this chapter, "Construction, Marking, and Lighting of Antenna Structures." Information regarding the inspection and maintenance of antenna structures requiring obstruction marking and lighting is also contained in Part 17 of this chapter.

"Part 17 of this chapter" refers to Part 17 of the Rules and Regulations. This part describes the limitations placed on antenna structures, and the provisions that must be made for lighting them.

Transmitter Output. In the amateur service, transmitter output must also meet standards of performance set down by the FCC. These output standards are spelled out in Section 97.73 of the regulations:

Spurious radiation from an amateur station being operated with a carrier frequency below 144 megacycles shall be reduced or eliminated in accordance with good engineering practice. This spurious radiation shall not be of sufficient intensity to cause interference in receiving equipment of good engineering design including adequate selectivity characteristics, which is tuned to a frequency or frequencies outside the frequency band of emission normally required for the type of emission being employed by the amateur station. In the case of A3 emission (amplitude-modulated telephony – see Table III at the end of this book) the amateur transmitter shall not be modulated to the extent that interfering spurious radiation occurs, and in no case shall the emitted carrier wave be amplitude-modulated in excess of 100 percent. Means shall be employed to insure that the transmitter is not modulated in excess of its modulation capability for proper technical operation. For the purposes of this section, a spurious radiation is any radiation from a transmitter which is outside the frequency band of emission normal for the type of transmission employed, including any component whose frequency is an integral multiple or submultiple of the carrier frequency (harmonics and subharmonics), spurious modulation products, key clicks and other transient effects, and parasitic oscillations. When using amplitude modulation on frequencies below 144 megacycles, simultaneous frequency modulation is not permitted and when using frequency modulation on frequencies below 144 megacycles simultaneous amplitude modulation is not permitted. The frequency of the emitted carrier wave shall be as constant as the state of the art permits.

License Terms. The periods of operator and station licenses are set forth in section 97.59:

(a) An amateur operator license is valid for a period of 5 years from the date of issuance, except the Novice Class which is valid for a period of 2 years.

(b) An amateur station license is valid for a period of 5 years from the date of issuance, except that an amateur station license issued to a Novice Class amateur operator licensee is valid for a period of 2 years from the date of issuance.

(c) All amateur station licenses, regardless of when issued, will expire on the same date as the licensee's amateur operator license.

Citizens Radio Service

Licensing requirements for the Citizens Radio Service are quite simple. There is no operator's license required for the normal use of Citizens Radio equipment. However, a station license must be obtained, and a commercial radio operator's license of the proper grade is also required for manually operated telegraphy. A commercial license is also necessary for anyone making any adjustments to a Citizens Radio transmitter during installation, testing, or servicing which may cause the transmitter to operate off frequency or in some other manner that would violate the rules of the FCC. For this reason, many manufacturers make the frequency-determining components of their sets "tamper-proof." A tamper-proof transmitter is one that operates on the correct frequency if it operates at all. Sealed chasses with the frequency-determining components mounted in them, and crystal-controlled oscillators are two techniques that are used to make Citizens Radio transmitters tamper-proof.

Station licenses for Citizens Radio Service are issued by the FCC at Washington, D. C. 20554. Nearly all such licenses are issued by mail. The forms for these station licenses are frequently supplied by the manufacturer with the equipment itself, with much of the technical description of the equipment already filled out. This simple licensing procedure can be used because the manufacturers have their products type-accepted or type-approved before they are marketed.

Convenient licensing, and a certain amount of misunderstanding over the purpose of Citizens Radio have led to some misuse of this type of equipment. The Rules describe the purpose of this service in Section 95.1 as follows:

> **...to provide for private short-distance radiocommunications service for the business or personal activities of licensees, for radio signaling, for the control of remote objects or devices by means of radio; all to the extent that these uses are not specifically prohibited in this part. They also provide for procedures whereby manufacturers of radio equipment to be used or operated in the Citizens Radio Service may obtain type acceptance and/or type approval of such equipment as may be appropriate.**

Classes of Stations. Licenses are granted in the four classes shown in Table II. Besides the limitations of the four classes shown in Table II, each class of transmitter is limited as to the type of emission. Section 95.47 of the Rules sets out the types of emission that may be used:

(a) Except as provided in paragraph (e) of this section, Class A stations in this service will normally be authorized to transmit radiotelephony only. However, the use of tone signals or signaling devices solely to actuate receiver circuits, such as tone operated squelch or selective calling circuits, the primary function of which is to establish or establish and maintain voice communications, is permitted. The use of tone signals solely to attract attention is prohibited.

(b) Class B stations in this service are authorized to use amplitude or frequency modulation, or on-off unmodulated carrier, and may be used for radiotelephony, to control remote objects or devices by means of radio, or to remotely actuate devices which are used as a means of attracting attention.

(c) Class C stations in this service are authorized to use amplitude tone modulation or on-off unmodulated carrier only, for the control of remote objects or devices by radio or for the remote actuation of devices which are used solely as a means of attracting attention. The transmission of any form of telegraphy, telephony or record communications by a Class C sta-

CLASS	USE	FREQUENCY RANGE (MHz)	POWER (Max. Watts Input)
A	Voice	462.550 - 462.725 467.550 - 467.725	60
B	Voice and Control	462.525 - 467.475	5
C	Control	26.995 - 27.225 27.255 72.08 - 75.64	5 30 1
D	Voice	26.965 - 27.225 27.255	5

Table II. Classes of Citizens Radio stations, frequencies, and power limitations. *

*** There is no provision here for random communications in the amateur bands. We will discuss this subject in more detail a little later on.**

tion is prohibited. Telemetering, except for the transmission of simple, short duration signals indicating the presence or absence of a condition or the occurrence of an event, is also prohibited.

(d) Class D stations in this service are authorized to use amplitude voice modulation, including single sideband and/or reduced or suppressed carrier, for radiotelephone communications only. However, the use of tone signals or signaling devices solely to actuate receiver circuits, such as tone operated squelch or selective calling circuits, the primary function of which is to establish or establish and maintain voice communications, is permitted. The use of tone signals solely to attract attention or for the control of remote objects or devices is prohibited.

(e) Other types of emission not described in paragraph (a) of this section may be authorized for Class A citizens radio stations upon a showing of need therefor. An application requesting such authorization shall fully describe the emission desired, shall indicate the bandwidth required for satisfactory communication, and shall state the purpose for which such emission is required. For information regarding the classification of emissions and the calculation of bandwidth, reference should be made to Part 2 of this chapter.

EMISSION LIMITATIONS

Section 95.49 shows the other limitations that apply to the emissions of the different classes of Citizens Radio transmitters (for the meaning of the different types of emission, see Table III at the end of this text):

(a) Each authorization issued to a Class A citizens radio station will show, as a prefix to the classification of the authorized emission, a figure specifying the maximum bandwidth to be occupied by the emission.

(b) All operation of a Class B citizens radio station (including tolerance and bandwidth occupied by the emission) shall be confined to the frequency band 462.525-467.475 MHz.

(c) (1) Except as provided in subparagraph (2) of this paragraph and except in the case of Class B citizens radio stations operating only on the frequency 465.00 MHz (see §95.41(b)), the maximum authorized bandwidth of the emission of any station employing amplitude modulation (Type A2 or A3 emission) shall be 8kHz and the maximum authorized bandwidth of the emission of any station employing frequency or phase modulation (Type F2 or F3 emission) shall be 40 kHz. The use of Type F2 or F3 emission in the frequency band 26.96-27.28 MHz is not authorized.

(2) Effective November 1, 1967, the maximum authorized bandwidth of Class A stations employing frequency or phase modulation (Type F2 or F3 emission) will be 20 kHz. Class A stations authorized before November 1, 1967 may continue to operate with maximum 40 kHz bandwidth until November 1, 1971.

(d) The mean power of emission shall be attenuated below the mean output power of the transmitter in accordance with the following schedule:

(1) On any frequency removed from the assigned frequency by more than 50 percent up to and including 100 percent of the authorized bandwidth: At least 25 decibels;

(2) On any frequency removed from the assigned frequency by more than 100 percent up to and including 250 percent of the authorized bandwidth: At least 35 decibels;

(3) On any frequency removed from the assigned frequency by more than 250 percent of the authorized bandwidth, at least the amounts indicated in the following table:

Maximum authorized power input to final radio frequency stage:	Attenuation (db)
Over 3 watts	50
3 watts or less	[1]40

[1] In the case of Class B stations having a maximum power input to the final radio frequency stage of 3 watts or less, any emission appearing on any frequency within a band allocated to industrial, scientific, and medical equipment under the provisions of Part 2 of this chapter shall be attenuated at least 30 db.

(e) When an unauthorized emission results in harmful interference, the Commission may, in its discretion, require appropriate technical changes in equipment to alleviate the interference.

Modulation Requirements. The modulation of Citizens-Band transmitters is also limited as set out in Section 95.51:

(a) When the radio frequency carrier of a station in this service is amplitude modulated, such modulation shall not exceed 100 percent on positive or negative peaks.

(b) Except as provided in paragraph (c) of this section and except in the case of Class B citizens radio stations operating only on the frequency 465.00 MHz (see §95.41(b)), the frequency deviation of any frequency modulated transmitter operated in this service shall not exceed ±15 kHz and the simultaneous amplitude modulation and frequency or phase modulation of a transmitter is not authorized.

(c) Effective June 1, 1968, the maximum frequency deviation for Class A stations employing F2 or F3 emission is ±5 kHz: Provided, That stations authorized prior to November 1, 1967, located 100 miles or more from the center of urbanized areas of 200,000 or more population may continue to operate with a frequency deviation of ± 15 kHz until November 1, 1971.

(d) Class A stations authorized on or after November 1, 1967, shall be provided with a device which automatically will prevent modulation in excess of that specified in this subpart which may be caused by greater than normal audio level. Class A stations authorized before November 1, 1967, will be required to comply with the provisions of this paragraph by November 1, 1971: Provided, however, That the requirements of this paragraph shall not apply to transmitters authorized to operate as mobile stations with a maximum plate power input to the final radio frequency stage of 3 watts or less.

(e) Each transmitter of a Class A station which is equipped with a modulation limiter in accordance with the provisions of paragraph (d) of this section shall also be equipped with an audio low-pass filter. This audio low-pass filter shall be installed between the modulation limiter and the modulated stage and, at audio frequencies between 3 kHz and 20 kHz, shall have an attentuation greater than the attenuation at 1 kHz by at least:

$$60 \log_{10} (f/3) \text{ decibels}$$

where "f" is the audio frequency in kHz. At audio frequencies above 20 kHz, the attenuation shall be at least 50 decibels greater than the attenuation at 1 kHz.

OPERATING REQUIREMENTS

The operating requirements set out in subpart D of Part 95 of the Rules reflect some of the misunderstandings that have cropped up about the use of Citizens Radio equipment.

§95.83 Prohibited Uses.

(a) A Citizens radio station shall not be used:

(1) For engaging in radio communications as a hobby or diversion, i.e., operating the radio station as an activity in and of itself.

NOTE: The following are typical, but not all inclusive, examples of the types of communications evidencing a use of Citizens radio as a hobby or diversion which are prohibited under this rule:

"You want to give me your handle and I'll ship you out a card the first thing in the morning;" or "Give me your 10-20 so I can ship you some wallpaper." (Communications to other licensees for the purpose of exchanging so-called "QSL" cards.)

"I'm just checking to see who is on the air."

"Just calling to see if you can hear me. I'm at Main and Broadway."

"Just heard your call sign and thought I'd like to get acquainted;" or "Just passing through and heard your call sign so I thought I'd give you a shout."

"Just sitting here copying the mail and thought I'd give you a call to see how you were doing." (Referring to an intent to communicate based solely on hearing another person engaged in the use of his radio.)

"My 10-20 is Main and Broad Streets. Thought I'd call so I can see how well this new rig is getting out."

"Got a new mike on this rig and thought I'd give you a call to find out how my modulation is."

"Just thought I would give you a shout and let you know I am still around. Thanks for coming back."

"Clear with Venezuela. Just thought I'd let you know I was copying you up here."

"Thought I'd give you a shout and see if you knew where the unmodulated carrier was coming from."

"Just thought I'd give you a call to find out how the skip is coming in over at your location."

"Go ahead breaker. What kind of a rig are you using? Come back with your 10-20."

(2) For any purpose, or in connection with any activity, which is contrary to Federal, State, or local law.

(3) For the transmission of communications containing obscene, indecent, or profane words, language, or meaning.

(4) To carry communications for hire, whether the remuneration or benefit received is direct or indirect.

(5) To communicate with stations authorized or operated under the provisions of other parts of this chapter, with unlicensed stations, or with U. S. Government or foreign stations, except for communications pursuant to §§95.85(b) and 95.121 and, in the case of Class A stations, for communications with U. S. Government stations in those cases which require cooperation or coordination of activities.

(6) For any communication not directed to specific stations or persons, except for: (i) Emergency and civil defense communications as provided in §§95.85(b) and 95.121, respectively, (ii) test transmissions pursuant to §95.93, and (iii) communications from a mobile unit to other units or stations for the sole purpose of requesting routing directions, assistance to disabled vehicles or vessels, information concerning the availability of food or lodging, or any other assistance necessary to a licensee in transit.

(7) To convey program material for retransmission, live or delayed, on a broadcast facility.

NOTE: A Class A, Class B, or Class D station may be used in connection with the administrative, engineering, or maintenance activities of a broadcasting station; a Class A, Class B, or Class C station may be used for control functions by radio which do not involve the transmission of program material; and a Class A, Class B, or Class D station may be used in the gathering of news items or preparation of programs: Provided, That the actual or recorded transmissions of the Citizens radio station are not broadcast at any time in whole or in part.

(8) To interfere maliciously with the communications of another station.

(9) For the direct transmission of any material to the public through public address systems or similar means.

(10) To transmit superfluous communications,

i.e., any transmissions not necessary to communications which are permissible.

(11) For the transmission of music, whistling, sound effects, or any material for amusement or entertainment purposes, or solely to attract attention.

(12) To transmit the word "MAYDAY" or other international distress signals, except when a ship, aircraft, or other vehicle is threatened by grave and imminent danger and requests immediate assistance.

(13) For transmitting communications to stations of other licensees which relate to the technical performance, capabilities, or testing of any transmitter or other radio equipment, including transmissions concerning the signal strength or frequency stability of a transmitter, except as necessary to establish or maintain the specific communication.

(14) For relaying messages or transmitting communications for a person other than the licensee or members of his immediate family, except: (i) Communications transmitted pursuant to §§95.85(b), 95.87(b)(7), and 95.121; and, (ii) upon specific prior Commission approval, communications between citizens radio stations at fixed locations where public telephone service is not provided.

(15) For advertising or soliciting the sale of any goods or services.

(16) For transmitting messages in other than plain language. Abbreviations, including nationally or internationally recognized operating signals, may be used only if a list of all such abbreviations and their meaning is kept in the station records and made available to any Commission representative on demand.

(b) A Class D station may not be used to communicate with, or attempt to communicate with, any unit of the same or another station over a distance of more than 150 miles.

(c) A licensee of a Citizens radio station who is engaged in the business of selling Citizens radio transmitting equipment shall not allow a customer to operate under his station license. In addition, all communications by the licensee for the purpose of demonstrating such equipment shall consist only of brief messages addressed to other units of the same station.

§95.85 Emergency Use.

(a) All Citizens radio stations shall give priority to the emergency communications of other stations which involve the immediate safety of life of individuals or the immediate protection of property.

(b) Any station in this service may be utilized during an emergency involving the immediate safety of life or the immediate protection of property for the transmission of emergency communications. When so used, certain provisions in this part concerning use of frequencies (§95.41(d)); prohibited uses (§95.83(a)(5) and (6)); operation by or on behalf of persons other than the licensee (§95.87); and duration of transmissions (§95.91(a) and (b)) shall not apply. However, any emergency use that necessitate taking advantage of these exceptions to usual requirements shall be subject to the following conditions:

(1) As soon as possible after the beginning of such emergency use, notice shall be sent to the Commission in Washington, D.C., and to the Engineer in Charge of the radio district in which the station is located, stating the nature of the emergency and the use to which the station is being put.

(2) The emergency use of the station shall be discontinued as soon as possible, and the Commission in Washington, D.C., and the Engineer in Charge, shall be notified immediately when such special use of the station is terminated. If the emergency use is of less than 24-hour duration, a single notice containing all of the required information will serve to comply with the notice requirements of this paragraph.

(3) Discontinuance of such special use of the authorized facilities.

(c) If the emergency use under paragraph (b) of this section extends over a period of 12 hours or more, notice shall be sent to the Commission in Washington, D.C., as soon as it is evident that the emergency has or will exceed 12 hours. The notice should include the identity of the stations participating, the nature of the emergency, and the use made of the stations. A single notice covering all participating stations may be submitted.

§ 95.87 Operation by, or on behalf of, persons other than the licensee.

(a) Transmitters authorized in this service must be under the control of the licensee at all times. A licensee shall not transfer, assign, or dispose of, in any manner, directly or indirectly, the operating authority under this station license, and shall be responsible for the proper operation of all units of the station.

(b) Citizens radio stations may be operated only by the following persons, except as provided in paragraph (c) of this section:

(1) The licensee;

(2) Members of the licensee's immediate family living in the same household;

(3) The partners, if the licensee is a partnership, provided the communications relate to the business of the partnership;

(4) The members, if the licensee is an unincorporated association, provided the communications relate to the business of the association;

(5) Employees of the licensee only while acting within the scope of their employment;

(6) Any person under the control or supervision of the licensee when the station is used solely for the control of remote objects or devices, other than devices used only as a means of attracting attention; and

(7) Other persons, upon specific prior approval of the commission shown on or attached to the station license, under the following circumstances:

(i) Licensee is a corporation and proposes to provide private radiocommunication facilities for the transmission of messages or signals by on or behalf of its parent corporation, another subsidiary of the parent corporation, or its own subsidiary. Any remuneration or compensation received by the licensee for the use of the radiocommunication facilities shall be governed by a contract entered into by the parties concerned and the total of the compensation shall not exceed the cost of providing the facilities. Records which show the cost of service and its nonprofit or cost-sharing basis shall be maintained by the licensee.

(ii) Licensee proposes the shared or cooperative use of a Class A station with one or more other licensees in this service for the purpose of communicating on a regular basis with units of their respective Class A stations, or with units of other Class A stations if the communications transmitted are otherwise permissible. The use of these private radiocommunication facilities shall be conducted pursuant to a written contract which shall provide that contributions to capital and operating expense shall be made on a nonprofit cost-sharing basis, the cost to be divided on an equitable basis among all parties to the agreement. Records which show the cost of service and its nonprofit, cost-sharing basis shall be maintained by the licensee. In any case, however, licensee must show a separate and independent need for the particular units proposed to be shared to fulfill his own communications requirements.

(iii) Other cases where there is a need for other persons to operate a unit of licensee's radio station. Requests for authority may be made either at the time of filing of the application for station license or thereafter by letter. In either case, the licensee must show the nature of the proposed use and that it relates to an activity of the licensee, how he proposes to maintain control over the transmitters at all times, and why it is not appropriate for such other person to obtain a station license in his own name. The authority, if granted, may be specific with respect to the names of persons who are permitted to operate, or may authorize operation by unnamed persons for specific purposes. This authority may be revoked by the Commission in its discretion, at any time.

(c) An individual who was formerly a citizen radio station licensee shall not be permitted to operate any citizens radio station of the same class licensed to another person until such time as he again has been issued a valid radio station license of that class, when his license has been:

(1) Revoked by the Commission.

(2) Surrendered for cancellation after the institution of revocation proceedings by the Commission.

(3) Surrendered for cancellation after a notice of apparent liability to forfeiture has been served by the Commission.

§95.91 Duration of Transmissions.

(a) All communications or signals, regardless of their nature, shall be restricted to the minimum practicable transmission time.

The radiation of energy shall be limited to transmissions modulated or keyed for actual permissible communications, tests or control signals. Continuous or uninterrupted transmissions from a single station or between a number of communicating stations is prohibited except for communications involving the immediate safety of life or property.

(b) Communications between or among Class D stations shall not exceed 5 consecutive minutes. At the conclusion of this 5-minute period, or upon termination of the exchange if less than 5 minutes, the station transmitting and the stations participating in the exchange shall remain silent for a period of at least 5 minutes and monitor the frequency or frequencies involved before any further transmissions are made. However, for the limited purpose of acknowledging receipt of a call, such a station or stations may answer a calling station and request that it stand by for the duration of the silent period. The time limitations contained in this paragraph may not be avoided by changing the operating frequency of the station and shall apply to all transmissions of an operator who, under other provisions of this part, may operate a unit of more than one citizens radio station.

(c) The transmission of audible tone signals or a sequence of tone signals for the operation of the tone operated squelch or selective calling circuits in accordance with §95.47 shall not exceed a total of 15 seconds duration. Continuous transmission of a subaudible tone for this purpose is permitted. For the purposes of this section, any tone or combination of tones having no frequency above 150 Hertz shall be considered subaudible.

(d) The transmission of permissible control signals shall be limited to the minimum practicable time necessary to accomplish the desired control or actuation of remote objects or devices. The continuous radiation of energy for periods exceeding 3 minutes duration for the purpose of transmission of control signals shall be limited to control functions requiring at least one or more changes during each minute of such transmission. However, while it is actually being used to control model aircraft in flight by means of interrupted tone modulation of its carrier, a citizens radio station may transmit a continuous carrier without being simultaneously modulated if the presence or absence of the carrier also performs a control function. An exception to the limitations contained in this paragraph may be authorized upon a satisfactory showing that a continuous control signal is required to perform a control function which is necessary to insure the safety of life and property.

§95.93 Tests and Adjustments.

All tests or adjustments of citizens radio transmitting equipment involving an external connection to the radio frequency output circuit shall be made using a nonradiating dummy antenna. However, a brief test signal either with or without modulation, as appropriate, may be transmitted when it is necessary to adjust a transmitter to an antenna for a new station installation or for an existing installation involving a change of antenna or change of transmitters, or when necessary for the detection, measurement, and suppression of harmonic or other spurious radiation. Test transmissions using a radiating antenna shall not exceed a total of 1 minute during any 5-minute period, shall not interfere with communications already in progress on the operating frequency, and shall be properly identified as required by §95.95, but may otherwise be unmodulated as appropriate.

§95.95 Station Identification.

(a) The call sign of a citizens radio station shall consist of three letters followed by four digits.

(b) Each transmission of the station call sign shall be made in the English language by each unit, shall be complete, and each letter and digit shall be separately and distinctly transmitted. Only standard phonetic alphabets, nationally or internationally recognized, may be used in lieu of pronunciation of letters for voice transmission of call signs. A unit designator or special identification may be used in addition to the station call sign but not as a substitute therefor.

(c) Except as provided in paragraph (d) of this section, all transmissions from each unit of a citizens radio station shall be identified by the transmission of its assigned call sign at the beginning and end of each transmission or series of transmissions directed to or exchanged with a unit of the same station or units of other stations. Each required identification shall include not only the call sign of the station unit transmitting, but also the call sign of the station or stations with which the transmitting unit is communicating, or attempting to communicate. In the case of communications between units of the same station (intrastation), after identifying itself by its assigned call sign, the transmitting unit may identify the other units by unit designators. For communications between units of different stations (interstation), the complete sign of all stations involved must be transmitted. If the call sign of the station being called is not known, the name or trade name may be used, but when contact has been made the called station shall thereafter be identified by its call sign. Examples of proper identification procedure are set forth at the end of this paragraph. Where transmissions or exchanges of transmissions of greater length are permitted by this part, the identification shall also be transmitted at least every 15 minutes. Each transmission or exchange of transmissions conducted on different frequencies shall be fully and separately identified in accordance with the foregoing on each frequency used.

EXAMPLES OF PROPER IDENTIFICATION

Intrastation communications:

(1) Calling: "KZZ 0001 base, calling unit 2."
Response: "KZZ 0001 unit 2, to base, over."
Clearing: "KZZ 0001 base, clear with unit 2" and "KZZ 0001 unit 2, clear with base."

(2) Calling: "KZZ 0001 unit 1, calling unit 3."
Response: "KKZ 0001 unit 3, to unit 1, over."
Clearing: "KZZ 0001 unit 1, clear with unit 3" and "KZZ 0001 unit 3, clear with unit 1."

Interstation communications:
Calling: "KZZ 0001 calling KZZ 0002," or "KZZ 0001 calling KZZ 0002 unit 3" (if appropriate).
Response: "KZZ 0002 to KZZ 0001, over."
Clearing: "KZZ 0001 clear with KZZ 0002," and "KZZ 0002 clear with KZZ 0001."

(d) Unless specifically required by the station authorization, the transmission of a citizens radio station need not be identified when the station (1) is a Class A station which automatically retransmits the information received by radio from another station which is properly identified or (2) is not being used for telephony emission.

(e) In lieu of complying with the requirements of paragraph (c) of this section, Class A base stations, fixed stations, and mobile units when communicating with base stations may identify as follows:

(1) Base stations and fixed stations of a Class A radio system shall transmit their call signs at the end of each transmission or exchange of transmissions, or once each 15-minute period of a continuous exchange of communications.

(2) A mobile unit of a Class A station communicating with a base station of a Class A radio system on the same frequency shall transmit once during each exchange of transmissions any unit identifier which is on file in the station records of such base station.

(3) A mobile unit of Class A stations communicating with a base station of a Class A radio system on a different frequency shall transmit its call sign at the end of each transmission or exchange of transmissions, or once each 15-minute period of a continuous exchange of communications.

§95.105 Current copy of rules required.

Each licensee in this service shall maintain as a part of his station records a current copy of Part 95, Citizens Radio Service, of this chapter.

We have gone into the details of Citizens Radio operating requirements because of misunderstandings about this type of radio service and misuse of it. Each radio service has its own operating requirements as you will see in the next section. The Citizens Radio Service has less demanding requirements than other radio services but they are important nonetheless.

Operational Requirements

The operational requirements of radio stations fall into two types -- the technical operation, whereby the required technical standards are maintained, and the actual operation, or use, of the transmitter.

TECHNICAL OPERATION

The Technical operation requirements of the different classes of radio stations are set out in the Rules and Regulations. As an example of the kind of technical operation that is required, we can take the regulations that apply to standard AM broadcasting stations.

Determination of Operating Power. Section 73.51 tells how operating power is determined:

(a) Except as provided in paragraph (b) of this section, the operating power shall be determined by the direct method, i.e., as the product of the antenna resistance at the operating frequency (see §73.54) and the square of the antenna current at this frequency, measured at the point where the antenna resistance has been determined.

(b) The operating power shall be determined on a temporary basis by the indirect method described in paragraphs (c) and (d) of this section, in the following circumstances: (1) In an emergency, where the authorized antenna system has been damaged by causes beyond the control of the licensee or permittee (see §73.45), or (2) pending completion of authorized changes in the antenna system, or (3) if changes occur in the antenna system or its environment which affect or appear likely to affect the value of antenna resistance or (4) if the antenna current meter becomes defective (see §73.58). Prior authorization for determination of power by the indirect method is not required. However, an appropriate notation shall be made in the operating log.

(c) (1) Operating power is determined by the indirect method of applying an appropriate factor to the plate input power, in accordance with the following formula:

$$\text{Operating power} = E_p \times I_p \times F$$

Where:

E_p = Plate voltage of the final radio stage

I_p = Total plate current of the final radio stage

F = Efficiency factor

(2) The value of F applicable to each mode of operation shall be entered in the operating log for each day of operation, with a notation as to its derivation. This factor shall be established by one of the methods described in paragraph (d) of this section, which are listed in order of preference. The product of the plate current and plate voltage, or alternatively, the computed operating power, shall be entered in the operating log under an appropriate heading for each log entry of plate current and plate voltage.

(d) (1) If the transmitter and the power utilized during the period of indirect power determination are the same as have been authorized and utilized for any period of regular operation, the factor F shall be the ratio of such authorized power to the corresponding plate input power of the transmitter for regular conditions of operation, computed with values of plate voltage and plate current obtained from the operating logs of the station for the last week of regular operation. However, if the station has been regularly authorized for operation with directional antenna, and temporary authority has been granted for nondirectional operation with regularly authorized power, during the period that power is being determined indirectly, an adjusted factor F shall be employed, which is derived by dividing the factor, as determined above, by a constant (0.925 for authorized powers of 5 kw, or less; 0.95 for powers above 5 kw.).

(2) If a station has not been previously in regular operation with the power authorized for the period of indirect power determination, if a new transmitter has been installed, or if, for any other reason, the determination of the factor F by the method described in paragraph (d) (1) of this section is impracticable:

(i) The factor F shall be obtained from the transmitter manufacturer's letter or test report retained in the station's files, if such a letter or test report specifies a unique value of F for the power level and frequency utilized; or

(ii) By reference to the following table:

Factor (F)	Method of modulation	Max. rated carrier power	Class of amplifier
0.70	Plate	0.25-1.0 kw	
.80	Plate	5 kw. & over	
.35	Low level	0.25 kw. & over	B
.65	Low level	0.25 kw. & over	BC[1]
.35	Grid	0.25 kw & over	

[1] All linear amplifier operation where efficiency approaches that of Class C operation.

(3) When the factor F is obtained from the table, this value shall be used even though the operating power may be less than the maximum rated carrier power of the transmitter.

Maintenance of Operating Power. Section 73.52 tells within what limits the operating power is to be maintained:

(a) The operating power of each station shall be maintained as near as practicable to the licensed power and shall not exceed the limits of 5 percent above and 10 percent below the licensed power, except that in an emergency when due to causes beyond control of the licensee it becomes impossible to operate with full licensed power, the station may be operated with reduced power for a period not to exceed 10 days, provided the Commission and the Engineer in Charge of the radio district in which the station is located shall be notified immediately after the emergency develops and also upon the resumption of licensed power.

(b) In addition to maintaining the operating power within the above limitations, stations employing directional antenna systems shall maintain the ratio of the antenna currents in the elements of the system within 5 percent of that specified by the terms of the license or other instrument of authorization.

How Antenna Resistance and Reactance Is Determined. Section 73.54 prescribes these measurement standards, procedures and record keeping:

(a) The resistance of an omnidirectional series fed antenna shall be measured at the base of the antenna, without intervening coupling networks or components. For a shunt-excited antenna, the antenna resistance shall be measured at the point when the radiofrequency energy is fed to the slant wire or other feed wire circuit without intervening networks or components.

(b) The resistance and reactance of a directional antenna shall be measured at the point of common radiofrequency input to the directional antenna system. The following conditions shall obtain:

(1) The antenna shall be finally adjusted for the required radiation pattern.

(2) The reactance at the operating frequency and at the point of measurement shall be adjusted to zero, or as near thereto as practicable.

(c) (1) The resistance of an antenna shall be determined by the following procedure: A series of discrete measurements shall be made over a band of frequencies extending from approximately 25 kHz below the operating frequency to approximately 25 kHz above that frequency, at intervals of approximately 5 kHz. The measured values shall be plotted on a linear graph, with frequency as the abscissa and resistance as the ordinate. A smooth curve shall be drawn through the plotted values. The resistance value corresponding to the point of intersection of the curye and the ordinate representing the operating frequency of the station shall be the resistance of the antenna.

(2) For a directional antenna, the reactance of the antenna shall be determined by a procedure similar to that described in subparagraph (1) of this paragraph.

(d) The license of a station with a directional antenna, and authorized power of 5 kilowatts or less shall specify an antenna resistance 92.5 percent of that determined at the point of common input; for a station with directional antenna and authorized power exceeding 5 kilowatts the license shall specify an antenna resistance 95 percent of that determined at the point of common input.

(e) Applications for authority to determine power by the direct method shall specify the antenna or common point resistance, and shall include the following supporting information.

(1) Description of measurement method.

(2) A schematic diagram showing clearly all components of coupling circuits, the point of resistance measurement, location of antenna ammeter, connections to and characteristics of all tower lighting isolation circuits, static drains, and any other fixtures, sample lines, etc., connected to or supported by the antenna, including other antennas and associated circuits.

(3) Make and type of each calibrated instrument employed, manufacturer's rated accuracy, together with the date of last calibration of the instrument, the accuracy of the calibration, and the identity of the person or firm making the calibration.

(4) A tabulation of all measured data.

(5) Graph(s) plotted from this data.

(6) The qualifications of the engineer(s) making the measurements.

Modulation Requirements. Section 73.55 sets the modulation percentage requirements:

> The percentage of modulation shall be maintained as high as possible consistent with good quality of transmission and good broadcast practice. In no case is it to exceed 100 percent on negative peaks of frequent recurrence. Generally, it should not be less than 85 percent on peaks of frequent recurrence; but where necessary to avoid objectionable loudness modulation may be reduced to whatever level is necessary, even if the resulting modulation is substantially less than 85 percent on peaks of frequent recurrence.

Section 73.56 describes the requirements for modulation monitors:

(a) Each station shall have in operation, either at the transmitter or at the place the transmitter is controlled, a modulation monitor of a type approved by the Commission.

NOTE: Approved modulation monitors are included on the Commission's "Radio Equipment List, Part B, Aural Broadcast Equipment." Copies of this list are available for inspection at the Commission's office in Washington, D. C. and at each of its field offices.

(b) In the event that the modulation monitor becomes defective the station may be operated without the monitor pending its repair or replacement for a period not in excess of 60 days without further authority of the Commission: Provided, That:

(1) Appropriate entries shall be made in the maintenance log of the station showing the date and time the monitor was removed from and restored to service.

(2) The Engineer in Charge of the radio district in which the station is located shall be notified both immediately after the monitor is found to be defective and immediately after the repaired or replacement monitor has been installed and is functioning properly.

(3) The degree of modulation of the station shall be monitored with a cathode ray oscilloscope or other acceptable means.

(c) If conditions beyond the control of the licensee prevent the restoration of the monitor to service within the above allowed period, informal request in accordance with § 1.549 of this chapter may be filed with the Engineer in Charge of the radio district in which the station is operating for such additional time as may be required to complete repairs of the defective instrument.

(d) Each station operated by remote control shall continuously, except when other readings are being taken, monitor percent of modulation or shall be equipped with an automatic device to limit percent of modulation on negative peaks to 100.

Indicating Instruments. Section 73.58 describes the indicating instruments that are required:

(a) Each standard broadcast station shall be equipped with indicating instruments which conform with the specifications set forth in § 73.39 for measuring the dc plate circuit current and voltage of the last radio frequency amplified stage; the radio frequency base current of each antenna element; and, for stations employing directional antenna systems, the radio frequency current at the point of common input to the directional antenna.

(b) In the event that any one of these indicating instruments becomes defective when no substitute which conforms with the required specifications is available, the station may be operated without the defective instrument pending its repair or replacement for a period not in excess of 60 days without further authority of the Commission: Provided, That:

(1) Appropriate entries shall be made in the maintenance log of the station showing the date and time the meter was removed from and restored to service.

(2) The Engineer in Charge of the radio district in which the station is located shall be notified both immediately after the instrument is found to be defective and immediately after the repaired or replacement instrument has been installed and is functioning properly.

(3) If the defective instrument is the antenna current meter of a nondirectional station which does not employ a remote antenna ammeter, or if the defective instrument is the common point meter of a station which employs a directional antenna, and does not employ a remote common point meter, the operating power shall be determined by the indirect method in accordance with § 73.51 (c) and (d) during the entire time the station is operated without the antenna current meter or common point meter. However, if a remote antenna ammeter or a remote common point meter is employed and the antenna current meter or common point meter becomes defective, the remote meter may be used in determining operating power by the direct method pending the return to service of the regular meter, provided other meters are maintained at same value previously employed.

(c) If conditions beyond the control of the licensee prevent the restoration of the meter to service within the above allowed period, informal request in accordance with § 1.549 of this chapter may be filed with the Engineer in Charge of the radio district in which the station is located for such additional time as may be required to complete repairs of the defective instrument.

(d) Remote antenna ammeters and remote common point meters are not required; therefore, authority to operate without them is not necessary. However, if a remote antenna ammeter or common point meter is employed and becomes defective, the antenna base currents may be read and logged once daily for each mode of operation, pending the return to service of the regular remote meter.

Frequency Requirements. Section 73.59 sets out the frequency tolerance:

> The operating frequency of each station shall be maintained within 20 Hz of the assigned frequency.

§73.60 describes the frequency monitor requirements:

(a) The licensee of each station shall have in operation, either at the transmitter or at the place where the transmitter is controlled, a frequency monitor of a type approved by the Commission which shall be independent of the frequency control of the transmitter.

NOTE: Approved frequency monitors are included on the Commission's "Radio Equipment List, Part B, Aural Broadcast Equipment". Copies of this list are available for inspection at the Commission's office in Washington, D. C. and at each of its field offices.

(b) In the event that the frequency monitor becomes defective the station may be operated without the monitor pending its repair or replacement for a period not in

excess of 60 days without further authority of the Commission: Provided, That:

(1) Appropriate entries shall be made in the maintenance log of the station showing the date and time the monitor was removed from and restored to service.

(2) The Engineer in Charge of the radio district in which the station is located shall be notified both immediately after the monitor is found to be defective and immediately after the repaired or replacement monitor has been installed and is functioning properly.

(3) The frequency of the station shall be measured by an external source at least once each 7 days and the result entered in the maintenance log.

(c) If conditions beyond the control of the licensee prevent the restoration of the monitor to service within the above allowed period, informal request in accordance with § 1.549 of this chapter may be filed with the Engineer in Charge of the radio district in which the station is located for such additional time as may be required to complete repairs of the defective instrument.

You can see from these quotations from the Rules that nearly every aspect of the technical operation requirements for radio stations and equipment is closely regulated. These Rules help to insure that the many radio services and classes of stations will be able to perform their functions without interfering with one another.

OPERATING SCHEDULES

In addition to the equipment requirements in the operation of a radio transmitter, the operating or broadcasting schedule is also closely regulated by the FCC Rules.

Section 73.71 describes the minimum operating schedule for AM (standard broadcast) stations:

(a) All standard broadcast stations are required to maintain an operating schedule of not less than two-thirds of the total hours they are authorized to operate between 6 a.m. and 6 p.m., local standard time, and two-thirds of the total hours they are authorized to operate between 6 p.m. and midnight, local standard time, on each day of the week except Sunday: Provided, however, That stations authorized for daytime operation only need comply only with the minimum requirement for operation between 6 a.m. and 6 p.m.

(b) In the event that causes beyond a licensee's control make it impossible to adhere to the operating schedule in paragraph (a) of this section or to continue operating, the station may limit or discontinue operation for a period of not more than 10 days, without further authority of the Commission. However, the Commission and the Engineer in Charge of the radio district in which the station is located shall be immediately notified in writing if the station is unable to maintain the minimum operating schedule and shall be subsequently notified when the station resumes regular operation.

The "experimental period" in broadcasting is the time from 12 midnight to local sunrise (nighttime is the period from local sunset to 12 midnight). Section 73.72 provides for the control of operation of standard broadcast stations during this period:

The licensee of each standard broadcast station shall operate or refrain from operating its station during the experimental period as directed by the Commission in order to facilitate frequency measurement or for the determination of interference.

Section 73.73 provides for operation of stations pursuant to the schedule of operation specified by the FCC license.

If the license of a station specifies the hours of operation, the schedule so speci-

fied shall be adhered to except as provided in §§ 73.71 and 73.72.

LOGS

Much of the information about the operation of radio stations must be set down in the station logs. There are three separate logs: (1) Program log; (2) Operating log; and (3) Maintenance log. Section 73.111 covers the general requirements relating to logs for standard broadcast stations. Similar provisions apply to other commercial radio stations:

(a) The licensee or permittee of each standard broadcast station shall maintain program, operating and maintenance logs as set forth in §§ 73.112, 73.113, and 73.114. Each log shall be kept by the station employee or employees (or contract operator) competent to do so, having actual knowledge of the .facts required, who in the case of program and operating logs shall sign the appropriate log when starting duty, and again when going off duty.

(b) The logs shall be kept in an orderly and legible manner, in suitable form, and in such detail that the data required for the particular class of station concerned is readily available. Key letters or abbreviations may be used if proper meaning or explanation is contained elsewhere in the log. Each sheet shall be numbered and dated. Time entries shall be either in local standard or daylight saving time and shall be indicated accordingly.

(c) No log or preprinted log or schedule which becomes a log, or portion thereof, shall be erased, obliterated, or willfully destroyed within the period of retention provided by the provisions of this part. Any necessary correction shall be made only pursuant to §§ 73.112, 73.113, and 73.114, and only by striking out the erroneous portion, or by making a corrective explanation on the log or attachment to it as provided in those sections.

(d) Entries shall be made in the logs as required by §§ 73.112, 73.113, and 73.114. Additional information such as that needed for billing purposes or for the cueing of automatic equipment may be entered on the logs. Such additional information, so entered, shall not be subject to the restrictions and limitations in the Commission's rules on the making of corrections and changes in logs.

Section 73.115 provides for retaining the logs as records:

Logs of standard broadcast stations shall be retained by the licensee or permittee for a period of 2 years: Provided, however, That logs involving communications incident to a disaster or which include communications incident to or involved in an investigation by the Commission and concerning which the licensee or permittee has been notified, shall be retained by the licensee or permittee until he is specifically authorized in writing by the Commission to destroy them: Provided, further, That logs incident to or involved in any claim or complaint of which the licensee or permittee has notice shall be retained by the licensee or permittee until such claim or complaint has been fully satisfied or until the same has been barred by statute limiting the time for the filing of suits upon such claims.

Section 73.116 sets forth the rules about making the logs and records available:

The following shall be made available upon request by an authorized representative of the Commission:

(a) Program, operating and maintenance logs.

(b) Equipment performance measurements required by §73.47.

(c) Copy of most recent antenna resistance or common-point impedance measurements submitted to the Commission.

(d) Copy of most recent field intensity measurements to establish performance of directional antennas required by § 73.151.

SECRECY REQUIREMENTS

Most radio stations engaged in handling communications traffic are obliged to observe strict secrecy with regard to the content of the messages they handle. For instance, stations in the shipboard maritime service are governed by Section 83.174 of the Rules, which provide:

> **The master or the person responsible, as well as all persons who may have knowledge of the text or even of the existence of the radio communications transmitted or received by a station on board ship or of any information whatever obtained by means of the radiocommunication service of such station, shall be under the obligation of observing and insuring the secrecy of communications to the extent required by the Communications Act and the International Radio Regulations.**

Section 501 of the Communications Act provides:

> **Any person who willfully and knowingly does or causes or suffers to be done any act, matter, or thing, in this Act prohibited or declared to be unlawful, or who willfully or knowingly omits or fails to do any act, matter, or thing in this Act required to be done, or willfully and knowingly causes or suffers such omission or failure, shall, upon conviction, thereof, be punished for such offense, for which no penalty (other than a forfeiture) is provided in this Act, by a fine of not more than $10,000 or by imprisonment for a term not exceeding one year, or both; except that any person, having been once convicted of an offense punishable under this section, who is subsequently convicted of violating any provision of this Act punishable under this section, shall be punished by a fine of not more than $10,000 or by imprisonment for a term not exceeding two years, or both.**

Section 502 of the Communications Act provides:

> **Any person who willfully and knowingly violates any rule, regulation, restriction, or condition made or imposed by the Commission under authority of this Act, or any rule, regulation, restriction, or condition made or imposed by an international radio or wire communications treaty or convention, or regulations annexed thereto, to which the United States is or may hereafter become a party, shall, in addition to any other penalties provided by law, be punished, upon conviction thereof, by a fine of not more than $500 for each and every day during which such offense occurs.**

Section 605 of the Communications Act provides:

> **No person receiving or assisting in receiving, or transmitting, or assisting in transmitting, any interstate or foreign communications by wire or radio shall divulge or publish the existence, contents, substance, purport, effect, or meaning thereof, except through authorized channels of transmission or reception, to any person other than the addressee, his agent, or attorney, or to a person employed or authorized to forward such communication to its destination, or to proper accounting or distributing officers of the various communicating centers over which the communication may be passed, or to the master of a ship under whom he is serving, or in response to a subpoena issued by a court of competent jurisdiction, or on demand of other lawful authority; and no person not being authorized by the sender shall intercept any communication and divulge or publish the existence, contents, substance, purport, effect, or meaning of such intercepted communication to any person; and no person not being entitled thereto shall receive or assist in receiving any interstate or foreign communication by wire or radio and use the same or any information therein contained for his own benefit or for the benefit of another not entitled thereto; and no person having received such intercepted communication or having become acquainted with the contents, substance, purport, effect, or meaning of the same or any part thereof, knowing that such information was so obtained, shall divulge or publish the existence, contents, substance, purport, effect, or meaning of**

the same or any part thereof, or use the same or any information therein contained for his own benefit or for the benefit or another not entitled thereto: Provided, That this section shall not apply to the receiving, divulging, publishing, or utilizing the contents of any radio communication broadcast, or transmitted by amateurs or others for the use of the general public, or relating to ships in distress.

ORDER OF PRIORITY

Messages handled in the communications services all have places in the order of priority. The details of this order are slightly different for the different services. However, the general order of priority can be seen from the regulations that apply to radiotelegraph communications in the maritime mobile service. This priority is set forth in Section 83.177(a):

(a) The order of priority of radiotelegraph communications in the maritime mobile service of any frequency used for this service shall be as follows:

(1) Distress calls (including the international distress signal for radiotelegraphy), the international radiotelegraph alarm signal, the international radiotelephone alarm signal, distress messages, and distress traffic.

(2) Communications preceded by the international radiotelegraph urgency signal.

(3) Communications preceded by the international radiotelegraph safety signal.

(4) Communications relative to radio direction-finding bearings.

(5) Communications relative to the navigation and safe movement of aircraft.

(6) Communications relative to the navigation, movements, and needs of ships; including weather observation messages destined for an official meteorological service.

(7) Government communications for which priority right has been claimed.

(8) Service communications relating to the working of the radiocommunication service or to communications previously transmitted.

(9) All other communications.

Distress, alarm, urgent, and safety signals are described as follows:

§83.234 Distress Signals.

(a) The international radiotelegraph distress signal consists of the group "three dots, three dashes, three dots" (. . . - - - . . .), symbolized herein by SOS, transmitted as a single signal in which the dashes are slightly prolonged so as to be distinguished clearly from the dots.

(b) The international radiotelephone distress signal consists of the word MAYDAY, pronounced as French expression "m'aider".

(c) These distress signals indicate that a mobile station is threatened by grave and imminent danger and requests immediate assistance.

§83.245 Radiotelegraph and radiotelephone alarm signals.

(a) The international radiotelegraph alarm signal consists of a series of twelve dashes sent in one minute, the duration of each dash being four seconds and the duration of the interval between consecutive dashes one second. The purposes of this special signal is the actuation of automatic devices giving the alarm to attract the attention of the operator when there is no listening watch on the distress frequency.

(b) The international radiotelephone alarm signal consists of two substantially sinusoidal audio frequency tones transmitted alternately. One tone shall have a frequency of 2200 cycles per second and the other a frequency of 1300 cycles per second, the duration of each tone being 250 milliseconds. When generated by automatic means, the radiotelephone alarm signal shall be transmitted continuously for a period of at least 30 seconds, but not exceeding one minute; when generated by other means, the signal shall be transmitted as continuously as practicable over a period of approximately one minute. The purpose of this special signal is to attract the attention of the person on watch or to actuate automatic devices giving the alarm.

§83.247 Urgency signals.

(a) The urgency signal indicates that the calling station has a very urgent message to transmit concerning the safety of a ship, aircraft, or other vehicle, or the safety of a person. The urgency signal shall be sent only on the authority of the master or person responsible for the mobile station.

(b) In radiotelegraphy, the urgency signal consists of three repetitions of the group XXX, sent with the individual letters of each group, and the successive groups clearly separated from each other. It shall be transmitted before the call.

(c) In radiotelephony, the urgency signal consists of the word PAN, spoken three times and transmitted before the call.

(d) The urgency signal shall have priority over all other communications, except distress. All mobile and land stations which hear it shall take care not to interfere with the transmission of the message which follows the urgency signal.

§83.249 Safety signals.

(a) The safety signal indicates that the station is about to transmit a message concerning the safety of navigation or giving important meteorological warnings.

(b) In radiotelegraphy, the safety signal consists of three repetitions of the group TTT, sent with the individual letters of each group, and the successive groups clearly separated from each other. It shall be sent before the call.

(c) In radiotelephony, the safety signal consists of the word SECURITY, spoken three times and transmitted before the call.

(d) The safety signal and call shall be sent on one of the international distress frequencies (500 kHz radiotelegraph; 2182 kHz radiotelephone), or on the national distress frequency (156.80 MHz radiotelephone). However, stations which cannot transmit on a distress frequency may use any other available frequency on which attention might be attracted.

INSPECTIONS

All stations licensed by the FCC are subject to station inspection. For instance, the Rules provide even with respect to Citizens Radio stations, in Section 95.103:

> **All stations and records of stations in the Citizens Radio Service shall be made available for inspection upon the request of an authorized representative of the Commission made to the licensee or to his representative (see § 1.6 of this chapter). Unless otherwise stated in this part, all required station records shall be maintained for a period of at least 1 year.**

Similar provisions apply to broadcast stations in Section 73.97:

> **The licensee of any radio station shall make the station available for inspection by representatives of the Commission at any reasonable hour.**

The possibility of an inspection makes it particularly important to keep both the log books and the station equipment in good shape at all times. Many points covered by the Rules but not mentioned in this brief text may be checked on a station inspection. For this reason, it is especially important to get a copy of the rules that apply to the particular service you are engaged in to make sure that the station is operated according to these rules at all times. For example, posting of operator and station licenses may seem like an incidental thing of little importance, but the Rules specifically provide in Section 73.92 that this shall be done.

(a) The station license and any other instrument of station authorization shall be posted in a conspicuous place and in such manner that all terms are visible, at the place the licensee considers to be the principal control point of the transmitter. At all other control points listed on the station authorization, a photocopy of the station license and other instruments of station authorization shall be posted.

(b) The original operator license, or FCC

Form 759, of each station operator shall be posted at the place where he is on duty as an operator.

It is also important for the operator requirements set out in Section 73.93 to be met at all times:

(a) One or more operators holding a radio operator license or permit of a grade specified in this section shall be in actual charge of the transmitting system, and shall be on duty either at the transmitter location or at the remote control point. If operation by remote control has not been authorized, the transmitter, required monitors and other required metering equipment shall be readily accessible, clearly visible, and located sufficiently close to the operator at the normal operating position that deviations from normal indications of required instruments can be observed readily. If operation by remote control is authorized, the required controls and instruments shall be readily accessible, clearly visible, and located sufficiently close to the operator at the normal operating position that deviations from normal indications of required instruments can be observed readily.

(b) With the exception set forth in paragraph (f) of this section, adjustments of the transmitting system and inspection, maintenance, and required equipment performance measurements and required field strength measurements shall be performed only by a first class radiotelephone operator.

(c) A station using a non-directional antenna and with authorized power of 10 kilowatts or less shall have at least one first class radiotelephone operator, readily available at all times, either in full time employment, or, in the alternative, the licensee may contract in writing for the services on a part-time basis of one or more such operators. Signed contracts with part-time operators shall be kept in the files of the station and shall be made available for inspection upon request by an authorized representative of the Commission. A signed copy of contracts shall be forwarded to the Engineer in Charge of the radio district in which the station is located within three (3) days after the contract is signed.

(d) A station using a non-directional antenna, during periods of operation with authorized power in excess of 10 kilowatts, may employ first class radiotelephone operators, second class operators, or operators with the third class permit endorsed for broadcast station operation for routine operation of the transmitting system if the station has in full-time employment at least one first class radiotelephone operator and complies with the provisions of paragraphs (f) and (g) of this section.

(e) A station using a directional antenna system, which is required by the station authorization to maintain the ratios of the currents in the elements of the system within a tolerance which is less than 5 percent or the relative phases of those currents within a tolerance which is less than 3 degrees shall, without exception, employ first class radiotelephone operators who shall be on duty and in actual charge of the transmitting system as specified in paragraph (a) of this section during hours of operation with a directional radiation pattern. A station whose authorization does not specifically require therein the maintenance of phase and current relationships within closer tolerances than above specified shall employ first class radiotelephone operators for routine operation of the transmitting system during periods of directional operation, *Provided however*, That holders of second class licenses or third class permits endorsed for broadcast station operation, may be employed for routine operation of the transmitting system if the following conditions are met:

(1) The station must have in full-time employment at least one first class radiotelephone operator.

(2) The station shall be equipped with a type-approved phase (antenna) monitor fed by a sampling system installed and maintained pursuant to accepted standards of good engineering practice.

(3) At least once each day, 5 days each week, unless required more frequently by the terms of the station authorization, or rules governing operation by remote control (see Sections 73.67(a)(6) and 73.113(a)(4)) a

first class radiotelephone operator shall record the following observations in the station maintenance log for each directional radiation pattern used: (i) Common point current. (ii) Antenna base currents. (iii) Sample loop currents or remote antenna base currents and phase monitor indications. (iv) Antenna base current ratios, and remote antenna or sample loop current ratios, and the deviations in these ratios, in percent, from the licensed values. A station authorized to use the same directional radiation pattern during all hours of operation shall record these observations with successive readings not less than 12 hours apart.

(4) A partial proof of performance shall be made once each calendar year, with intervals between successive proofs not to exceed fourteen (14) months. The report of such proof measurements shall be prepared and filed as specified in paragraph (b) of Section 73.47.

(5) Field strength measurements shall be made at the monitoring points specified in the station authorization at least once each 30 days unless more frequent measurements are required by such authorization. The results of these measurements shall be entered in the station maintenance log. The licensee shall have readily available, and in proper working condition, field strength measuring equipment to perform these measurements.

(f) Subject to the conditions set forth in paragraphs (c), (d), and (e) of this section, the routine operation of the transmitting system may be performed by an operator holding a second class license or third class permit endorsed for broadcast station operation. Unless, however, performed under the immediate and personal supervision of an operator holding a first class radiotelephone license, an operator holding a second class license or third class permit endorsed for broadcast station operation, may make adjustments only of external controls as follows:

(1) Those necessary to turn the transmitter on and off;

(2) Those necessary to compensate for voltage fluctuations in the primary power supply;

(3) Those necessary to maintain modulation levels of the transmitter within prescribed limits;

(4) Those necessary to effect routine changes in operating power which are required by the station authorization;

(5) Those necessary to change between non-directional and directional or between differing radiation patterns, provided that such changes require only activation of switches and do not involve the manual tuning of the transmitter final amplifier or antenna phasor equipment. The switching equipment shall be so arranged that the failure of any relay in the directional antenna system to activate properly will cause the emissions of the station to terminate.

(g) It is the responsibility of the station licensee to insure that each operator is fully instructed in the performance of all the above adjustments, as well as in other required duties, such as reading meters and making log entries. Printed step-by-step instructions for those adjustments which the lesser grade operator is permitted to make, and a tabulation or chart of upper and lower limiting values of parameters required to be observed and logged, shall be posted at the operating position. The emissions of the station shall be terminated immediately whenever the transmitting system is observed operating beyond the posted parameters, or in any other manner inconsistent with the rules or the station authorization, and the above adjustments are ineffective in correcting the condition of improper operation, and a first class radiotelephone operator is not present.

(h) When lesser grade operators are used, in accordance with paragraphs (d) or (e) of this section, for any period of operation using authorized power in excess of 10 kilowatts, or using a directional radiation pattern, the station licensee shall designate one first class radiotelephone operator in full-time employment as the chief operator who, together with the licensee, shall be responsible for the technical operation of the station. The station licensee shall notify the Engineer in Charge of the radio district in which the station is located of the name and license number of the designated chief operator. Such notification shall be by letter within three (3) days of such designation. A copy of the notification shall be posted with the chief operator's license.

(1) An operator designated as chief operator for one station may not be so designated concurrently at any other standard broadcast station.

(2) The station licensee shall vest such authority in, and afford such facilities to the chief operator as may be necessary to insure that the chief operator's primary responsibility for the proper technical operation of the station may be discharged efficiently.

(3) At such times as a regularly designated chief operator is unavailable or unable to act as chief operator (e.g., vacations, sickness), the station licensee shall designate another first class radiotelephone operator as acting chief operator on a temporary basis. Within three days of the date such action is taken, the Engineer in Charge of the radio district in which the station is located shall be notified by the licensee by letter of the name and license number of the acting chief operator, and shall be notified by letter, again within three days of the date when the regularly designated chief operator returns to duty.

(4) The designated chief operator may serve as a routine duty transmitter operator at any station only to the extent that it does not interfere with the efficient discharge of his responsibilities as listed below. (i) The inspection and maintenance of the transmitting system including the antenna system and required monitoring equipment. (ii) The accuracy and completeness of entries in the maintenance log. (iii) The supervison and instruction of all other station operators in the performance of their technical duties. (iv) A reveiw of completed operating logs to determine whether technical operation of the station has been in accordance with the rules and terms of the station authorization. After review, the chief operator shall sign the log and indicate the date of such review. If the review of the operating logs indicates technical operation of the station is in violation of the rules or the terms of the station authorization, he shall promptly initiate corrective action. The review of each day's operating log shall be made within 24 hours, except that, if the chief operator is not on duty during a given 24 hour period, the logs must be reviewed within two hours after his next appearance for duty. In any case, the time before review shall not exceed 72 hours.

(i) The operator on duty at the transmitter or remote control point, may, at the discretion of the licensee and the chief operator, if any, be employed for other duties or for the operation of another radio station or stations in accordance with the class of operator's license which he holds and the rules and regulations governing such other stations; *Provided, however*, That such other duties shall not interfere with the proper operation of the standard broadcast transmitting system and keeping of required logs.

(j) At all standard broadcast stations, a complete inspection of the transmitting system and required monitoring equipment in use, shall be made by an operator holding a first class radiotelephone license at least once each day, 5 days each week, with an interval of no less than 12 hours between successive inspections. This inspection shall include such tests, adjustments, and repairs as may be necessary to insure operation in conformance with the provisions of this subpart and the current station authorization.

VIOLATION NOTICES

Special provisions are made by the FCC for monitoring radio stations. These monitoring, or listening, posts can tell if a radio transmitter is operating properly.

If there is some defect in the operation of a radio station that violates the Rules and Regulations of the FCC, a note of the violation is sent to the holder of the station license. The provisions of Section 83.601 apply to stations on land in the maritime service. However, similar provisions apply to the other services as well:

> Any person receiving official notice of a violation of the terms of the Communications Act, any legislative act, Executive order, treaty to which the United States is a party, terms of a station or operator license, or the rules and regulations of the Federal Communications Commission, shall, within 10 days from such receipt, send a written answer, in duplicate, to the office of the Commission originating the official notice. If an answer cannot be sent, or an acknowledgement made within such 10-day period by reason of illness or other unavoidable circumstances, acknowledgement and answer shall be made at the earliest practicable date with a satisfactory explanation of the delay. The answer to each notice shall be complete in itself and shall not be abbreviated by references to other communications or answers to other notices. The answer shall contain a full explanation of the incident involved and shall set forth the action taken to prevent a continuation or recurrence thereof. If the notice relates to lack of attention to, or improper operation of the station, or to log or watch discrepancies, the answer shall give the name and license number of the licensed operator on duty.

Be sure you know the requirements for answering violation notices that apply to the particular service that you are in. Failure to respond properly to a notice of violation can result in license suspension.

LICENSE RENEWALS

Of course, the normal thing to do with either a station or an operator's license is to have it renewed when it expires. You should know the license renewal requirements for whatever license you hold. For example, the Novice amateur license is not renewable. Therefore, if you wish to continue operating after your Novice license expires, you must make provisions for obtaining a higher class of amateur license.

The following are the provisions that apply to the renewal and replacement requirements for commercial radio operators. You can get the corresponding requirements for other kinds of licenses by referring to the volume of the FCC Rules that covers that particular service.

Higher Class License. Section 13.26 describes the canceling of a license by the issuance of a higher class license, as follows:

> If the holder of a license qualifies for a higher class in the same group, the license held will be canceled upon the issuance of the new license. Similarly, if the holder of a restricted operator permit qualifies for a first- or second-class operator license of the corresponding type, the permit held will be canceled upon issuance of the new license.

Renewals. Rules regarding renewals are set forth in Section 13.28 as follows:

> A restricted radiotelephone operator permit normally is issued for the lifetime of the holder and need not be renewed. A temporary limited radiotelegraph second-class operator license is not renewable. A license of any other class may be renewed without examination provided that the service record on the reverse side of the license (see §§ 13.91 to 13.94) shows at least two years of satisfactory service in the aggregate during the license term and while actually employed as a radio operator under that license. If this two-year renewal service requirement is not fulfilled, but the service record shows at least one year of satisfactory service in the aggregate during the last three years of the license term and while actually employed as a radio operator under that license, the license may be renewed upon the successful completion of a renewal examination, which may be taken at any time during the final year of the license term or during a one-year period of grace after the date of expiration of the license sought to be renewed. The renewal examination will consist of the highest numbered examination element normally required for a new license of the class southt to be renewed,

> **plus the code test (if any) required for such new license. If the renewal examination is not successfully completed before expiration of the aforementioned one-year period of grace, the license will not be renewed on any basis.**
>
> **NOTE: By order dated and effective April 4, 1951, the Commission temporarily waived the requirement of prior service as a radio operator or examination for renewal in the case of any applicant for renewal of his commercial radio operator license. This order is applicable to commercial radio operator licenses which expired after June 30, 1950 until further order of the Commission.**

Duplicates. A license that has been lost or destroyed can be replaced as described in Section 13.71.

> **(a) An operator whose license or permit has been lost, mutilated, or destroyed shall immediately notify the Commission. If the authorization is of the diploma form, a properly executed application for duplicate should be submitted to the office of issue. If the authorization is of the card form (Restricted Radiotelephone Operator Permit), a properly executed application for replacement should be submitted to the Federal Communications Commission, Gettysburg, Pa., 17325. In either case the application shall embody a statement of the circumstances involved in the loss, mutilation, or destruction of the license or permit. If the authorization has been lost, the applicant must state that reasonable search has been made for it, and, further, that in the event it be found, either the original or the duplicate (or replacement) will be returned for cancellation. If the authorization is of the diploma form, the applicant should also submit documentary evidence of the service that has been obtained under the original authorization, or a statement embodying that information.**
>
> **(b) The holder of any license or permit whose name is legally changed may make application for a replacement document to indicate the new legal name by submitting a properly executed application accompanied by the license or permit affected. If the authorization is of the diploma form, the application should be submitted to the office where it was issued. If the authorization is of the card form (Restricted Radiotelephone Operator Permit) it should be submitted to the Federal Communications Commission, Gettysburg, Pa., 17325.**

Section 13.72 provides:

> **When a duplicate or replacement operator license or permit has been requested, or request has been made for renewal upon service or for an endorsement or a verification card, the operator shall exhibit in lieu of the original document a signed copy of the application which has been submitted by him.**

Verification Cards. A verification card may be obtained as set forth in Section 13.73:

> **The holder of an operator license or permit of the diploma form (as distinguished from such document of the card form) may, by filing a properly executed application accompanied by his license or permit, obtain a verification card (Form 758-F). This card may be carried on the person of the operator in lieu of the original license or permit when operating any station at which posting of an operator license is not required: Provided, That the license is readily accessible within a reasonable time for inspection upon demand by an authorized Government representative.**

Record of Service and Maintenance Duties. Section 13.75 provides the following:

> **In every case where a station log or service and maintenance records are required to be kept, and where service or maintenance duties are performed which may affect the proper operation of a station, the responsible operator shall sign and date an entry in the log of the station concerned, or in the station maintenance records if no log is required, giving:**
>
> **(a) Pertinent details of all service and maintenance work performed by him or under his supervision;**

(b) His name and address; and

(c) The class, serial number and expiration date of his license:

Provided, That the responsible operator shall not be subject to requirements of paragraphs (b) and (c) of this section in relation to a station, or stations of one licensee at a single location, at which he is regularly employed as an operator on a full time basis and at which his license is properly posted.

Service Record Endorsement. The following requirements are set forth in Sections 13.91 - 13.94 regarding the endorsement of the service record on an operator's license.

> **A station licensee, or his duly authorized agent, or the master of a vessel acting as the agent of a licensee, shall endorse the service record appearing on said operator license, showing the call letters and types of emission of the station operated, the nature and period of employment, and quality of performance of duty.**
>
> **If the operator has operated more than three stations in the aviation service, the service may be shown by giving the name of the aviation chain or company in lieu of listing the call letters of the several stations.**
>
> **Credit will be allowed only for satisfactory service obtained under conditions that required the employment of licensed operators, or when obtained at United States Government stations.**
>
> **The holder of a radiotelegraph first- or second-class operator license, or a temporary limited radiotelegraph second-class operator license desiring an endorsement to be placed thereon attesting to an aggregate of at least 6 months' satisfactory service as a qualified operator on a vessel of the United States or an applicant for a temporary limited radiotelegraph second-class operator license under §13.5(d)(3) may, in the event documentary evidence cannot be produced, submit to any office of the Commission a statement under oath accompanied by the license to be endorsed, embodying the following:**
>
> **(a) Names of ships at which employed;**
> **(b) Call letters of stations;**
> **(c) Types of emission used;**
> **(d) Type of service performed as follows:**
> **(1) Manual radiotelegraph operation only; and**
> **(2) Transmitter control only; or**
> **(3) Combination of (1) and (2) running concurrently;**
> **(e) Whether service was satisfactory or unsatisfactory;**
> **(f) Period of employment;**
> **(g) Name of master, employer, licensee, or his duly authorized agent.**

SUMMARY

This text gives you a general idea of the kind of material found in the Rules and Regulations. You should become thoroughly familiar with those that apply to your particular service.

The Rules and Regulations contain most of the information you will need to know about the licensing and operating requirements for radio stations and operators. These Rules and Regulations are made to put into effect the provisions of the Federal Communications Act, as amended. Therefore, both the Rules and the Communications Act often contain provisions that relate to the same subject. Consequently, it is useful to have a copy of this Act of Congress as well as the Rules that apply to your particular service. The Act has been printed separately, and can also be ordered from the Superintendent of Documents, Government Printing Office, Washington, D. C., 20402.

TYPE OF MODULATION OF MAIN CARRIER	TYPE OF TRANSMISSION	SYMBOL
Amplitude	With no modulation	A0
	Telegraphy without the use of a modulating audio frequency (by on-off keying)	A1
	Telegraphy by the on-off keying of an amplitude modulating audio frequency, or audio frequencies, or by the on-off keying of the modulated emission (special case: an unkeyed emission amplitude modulated).	A2
	Telephony	
	Double sideband	A3
	Single sideband, reduced carrier	A3A
	Single sideband, suppressed carrier	A3J
	Two independent sidebands	A3B
	Facsimile (with modulation of main carrier either directly or by a frequency modulated subcarrier).	A4
	Facsimile - single sideband, reduced carrier	A4A
	Television - vestigial sideband	A5C
	Multichannel voice-frequency telegraphy - single sideband, reduced carrier	A7A
	Cases not covered by the above, e.g., a combination of telephony and telegraphy - two independent sidebands	A9B
Frequency (or Phase)	Telegraphy by frequency shift keying without the use of a modulating audio frequency: one of two frequencies being emitted at any instant	F1
	Telegraphy by the on-off keying of a frequency modulating audio frequency or by the on-off keying of a frequency modulated emission (special case: an unkeyed emission, frequency modulated)	F2
	Telephony	F3
	Facsimile by direct frequency modulation of the carrier	F4
	Television	F5
	Four-frequency diplex telegraphy	F6
	Cases not covered by the above, in which the main carrier is frequency modulated.	F9

TYPE OF MODULATION OF MAIN CARRIER	TYPE OF TRANSMISSION	SYMBOL
Pulsed	A pulsed carrier without any modulation intended to carry information (e.g., radar)	P0
	Telegraphy by the on-off keying of a pulsed carrier without the use of a modulating audio frequency	P1D
	Telegraphy by the on-off keying of a modulating audio frequency or audio frequencies, or by the on-off keying of a modulated pulse carrier (special case: an unkeyed modulated pulsed carrier).	
	Audio frequency or audio frequencies modulating the amplitude of the pulses.	P2D
	Audio frequency or audio frequencies modulating the width (or duration) of the pulses.	P2E
	Audio frequency or audio frequencies modulating the phase (or position) of the pulses.	P2F
	Telephony	
	Amplitude modulated pulses	P3D
	Width (or duration) modulated pulses	P3E
	Phase (or position) modulated pulses	P3F
	Code modulated pulses (after sampling and quantization)	P3G
	Cases not covered by the above in which the main carrier is pulse modulated	P9

Table III. Classification of Typical Emissions.

GOOD RESOLUTIONS

When you make a good resolution, put it into effect at once. To postpone it is deadly. Anything that can be done next month or next year can be done *now* -- or at least a start can be made toward it.

Millions of people dream about doing fine, worthwhile things. But only a few hundred people ever get around to actually doing these things.

The few hundred may not be as smart as the others -- may not be as talented, as capable, or as well educated. But they *act* and achieve concrete results while the plans and good resolutions of the millions fade into nothing.

Remember this when you make plans -- when you make good resolutions. Put your plans and resolutions into effect at once. Get started!

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RADIO • TELEVISION COMMUNICATIONS

nri

MAIL PROBLEMS

XMX

NATIONAL RADIO INSTITUTE • WASHINGTON, D. C.

MATH PROBLEMS

CXMX

STUDY SCHEDULE NO. CXMX

CPC1M768 **1968 EDITION** Printed in U. S. A.

This is the final lesson in your NRI course. No new concepts are introduced here. Instead, it is intended as a convenient review covering all types of questions you are likely to encounter in taking the FCC exam, which involve the use of mathematics. Using the various required formulas will not only serve to refresh your memory on certain points, but should serve as an excellent indicator to you of how thoroughly you have learned the material covered in preceding lessons.

This lesson also has another purpose; that is, as preparation for the examinations you will be required to take when applying for employment with many manufacturing and service organizations. This is often the first step in determining whether or not they can make use of your particular skills. If you fail the examination, there is little hope for employment with that concern.

These industry examinations also serve to point out exactly what we have told you throughout your training: Just to know the answer to a given question is not enough and is not an indication of skill. You must know the "hows" and "whys" of electronics to last long on any job. You may fool yourself by hurrying through lessons and learning just enough to answer the examination questions, but you won't fool an employer.

You have progressed too far now to permit any small difficulty to stand in your way. You can be justifiably proud of your accomplishments - a relatively small percentage of men have neither the ambition nor the courage to follow through to the end in a course of instruction such as you have completed.

Make this effort count. Don't hurry now, when success is so near. Remember, you can always study in haste and repent in leisure.

The lesson is divided into two parts. In the first part you will find 117 examination-type questions, generally arranged in an order of progressive difficulty.

When you have finished a problem, the correctness of your work can be verified by turning to the corresponding number in the second section of the lesson entitled "Answers."

It must be emphasized that this review is in no way intended as a "cram" device. Your training has been thorough and such practices are entirely unnecessary and undesirable. Although you may be able to pass a given exam by "cram" methods, and even obtain a job as a result of holding an FCC license, lack of real understanding becomes readily apparent to an employer and you would find yourself back where you started.

With this in mind, if you have difficulty with any problem, and if your understanding of the problem is still not perfectly clear after studying the answer, go back to the lesson text in which the material is covered and make a thorough review. For example, if you do not completely understand how a given formula is transposed, go back to the math book where the process is explained in detail. If you do not understand any part of the non-mathematical associated discussion, again go back to the original lesson text and review. The importance of this procedure cannot be over-emphasized.

When you have completed this lesson in the manner recommended and have sent your final exam to NRI for grading, make a final review of the rules and regulations contained in the Lessons 11CX and 12CX. If you do as we recommend, you will have no difficulty with the FCC exam.

Problems

1. State the three ordinary mathematical forms of Ohm's Law.

2. What is the resistance of a circuit if I = 5 amps and E = 30 volts?

3. If two resistors of 10 and 5 ohms are connected in series, what is the total resistance?

4. If two resistors of 10 and 15 ohms, respectively, are connected in parallel, what is their effective resistance?

5. A battery having an emf of 6 volts is connected in series with a 300-ohm resistor. What is the circuit current?

6. In a series dc circuit the current, as measured by an ammeter, is 0.05 ampere, and the resistance, as measured by an ohmmeter is 100 ohms. What is the applied emf?

7. Three resistors of 5, 10, and 20 ohms, are connected in parallel. What is their total effective resistance?

8. A 6-volt battery is to be charged at a 3-amp rate from a 115-volt line. What value of resistance should be connected in series with the battery?

9. The filament of a vacuum tube is rated at 250 ma and 5 volts. It is to be operated from a 6-volt battery. What is the value of the required series resistor?

10. The coil resistance of a relay is 600 ohms. The relay is designed to operate when 0.3 amp current passes through the coil. If operation is to be made from a 220-volt dc line, what value of resistance is needed in series with the coil?

11. Give the three basic formulas for calculating power in dc circuits.

12. What will be the heat dissipation, in watts, of a resistor of 50 ohms having a current of 0.2 amp passing through it?

13. What is the maximum rated current-carrying capacity of a resistor marked "5000 ohms 200 watts?"

14. If two 5-watt, 300-ohm resistors are connected in parallel, what are the power dissipation capabilities of the combination?

15. The input power to a transmitter is 500 watts. The radiated power from the antenna is 300 watts. What is the efficiency of the transmitter?

16. State the formula for determining (1) the quantity or charge of a capacitor; (2) the energy stored in a capacitor.

17. What is the formula used to determine the total capacitance of a group of capacitors connected in parallel?

18. What is the formula used to determine the total capacitance of a group of capacitors connected in series?

19. If capacitors of 5, 3, and 7 μf are connected in series, what is the total capacitance?

20. If capacitors of 10, 20, and 30 μf are connected in parallel, what is the total capacitance?

21. Given two identical mica capacitors of 0.2 μf capacitance each. One is charged to a potential of 116 volts and disconnected from the charging circuit. The charged capacitor is then connected in parallel with the uncharged capacitor. What voltage will appear across the two capacitors connected in parallel?

22. State the mathematical formula for the energy stored in the magnetic field surrounding an inductance carrying an electric current.

23. What is the formula for determining wavelength when the fre-

quency in kilocycles is known?

24. If the period of one complete cycle of a radio wave is 0.000001 second, what is the wavelength?

25. What is the effective value of a sine wave in relation to its peak value?

26. What is the seventh harmonic of 360 kc?

27. What factors must be known in order to determine the power factor of an alternating current circuit?

28. In a circuit consisting of an inductance having a reactance of 100 ohms and a resistance of 100 ohms, what will be the phase angle of the current with respect to the voltage?

29. State Ohm's Law for ac circuits.

30. Neglecting distributed capacitance, what is the reactance of a 6 millihenry choke coil at a frequency of 500 kc?

31. What is the reactance value of a capacitor of 0.02 μf at a frequency of 20 kc?

32. Given a series circuit consisting of a resistance of 4 ohms, an inductive reactance of 4 ohms, and a capacitive reactance of 1 ohm. The applied circuit alternating emf is 50 volts. What is the voltage drop across the inductance?

33. What is the impedance of a solenoid, if its resistance is 5 ohms and 0.3 amp flows through the winding when 110 volts at 60 cycles is applied to the solenoid?

34. State the formula for determining the resonant frequency of a circuit where the inductance and capacitance are known.

35. Given a series-resonant circuit consisting of a resistance of 6.5 ohms, and equal inductive and capacitive reactances of 175 ohms. What is the voltage drop across the inductance when the applied potential is 260 volts?

36. Given a series-resonant circuit consisting of a resistance of 6.5 ohms, and equal inductive and capacitive reactances of 175 ohms. What is the voltage drop across the resistance, assuming the applied circuit potential is 260 volts?

37. Explain how you would determine the value of cathode bias resistance necessary to provide correct grid bias for any particular amplifier.

38. Given the following vacuum tube constants, E_p = 1000 volts, I_p = 150 ma, I_g = 10 ma, and grid leak = 5000 ohms, what would be the value of dc grid-bias voltage?

39. What is the percentage regulation of a power supply with a no-load voltage output of 126.5 volts and a full-load voltage output of 115 volts?

40. If a 1500-kc radio wave is modulated by a 2000-cycle sine-wave tone, what frequencies are contained in the output wave?

41. State the formula for determining the percentage modulation in an AM system.

42. If a ship telephone station is assigned the frequency of 2738 kc and the maximum tolerance is 0.04 percent, what are the highest and lowest frequencies within the tolerance limits?

43. Define the term "decibel."

44. A ship radiotelephone transmitter operates on 2738 kc. At a certain point distant from the transmitter the 2738-kc signal has a measured field of 147 mv per meter. The second harmonic field at the same point is measured as 405 μv per meter. To the nearest whole unit in decibels, how much has the harmonic emission been attenuated below the 2738-kc fundamental?

45. If a superheterodyne receiver is tuned to a desired signal at 1000 kc, and its conversion oscillator is operating at 1300 kc, what would be

the frequency of an incoming signal which would possibly cause "image" reception?

46. How much energy is consumed in 20 hours by a radio receiver rated at 60 watts?

47. A 6-volt storage battery has an internal resistance of 0.01 ohm. What current will flow when a 3-watt, 6-volt lamp is connected?

48. What determines the synchronous speed of a synchronous motor?

49. A milliammeter with a full-scale deflection of 1 ma and a resistance of 25 ohms was used to measure an unknown current by shunting the meter with a four-ohm resistor. It then read 0.4 ma. What was the unknown current value?

50. If a 0-1 dc milliammeter is to be converted into a voltmeter with full-scale calibration 100 volts, what value of series resistance must be connected in series with the milliammeter?

51. If a heterodyne frequency meter, having a calibrated range of 1000 to 5000 kc, is used to measure the frequency of a transmitter operating on approximately 500 kc by measurement of the second harmonic of the transmitter, and the indicated measurement was 1008 kc, what is the actual frequency of the transmitter output?

52. If a frequency meter having an over-all error proportional to the frequency, is accurate to 10 cycles when set at 600 kc, what is its error in cycles when set at 1110 kc?

53. What is the total reactance of two inductors, connected in series, with zero mutual inductance?

54. If the mutual inductance between two coils is 0.1 henry, and the coils have inductances of 0.2 and 0.8 henry, respectively, what is the coefficient of coupling?

55. When two coils of equal inductance are connected in series with unity coefficient of coupling and their fields in phase, what is the total inductance of the two coils?

56. A potential of 110 volts is applied to a series circuit containing an inductive reactance of 25 ohms, a capacitive reactance of 10 ohms, and a resistance of 15 ohms. What is the phase relationship between the applied voltage and the current flowing in the circuit?

57. What is the reactance of a capacitor at the frequency of 1000 kc if the reactance is 600 ohms at 800 kc?

58. If an alternating current of 5 amp flows in a series circuit composed of 12 ohms resistance, 15 ohms inductive reactance, and 40 ohms capacitive reactance, what is the voltage drop across the circuit?

59. If a lamp, rated at 100 watts and 115 volts, is connected in series with an inductive reactance of 355 ohms and a capacitive reactance of 130 ohms across a voltage of 220 volts, what is the current value through the lamp?

60. If an ac series circuit has a resistance of 12 ohms, an inductive reactance of 7 ohms, and a capacitive reactance of 7 ohms, at the resonant frequency, what will be the total impedance at twice the resonant frequency?

61. A series circuit contains reactance, inductive reactance, and capacitive reactance. The resistance is 7 ohms, the inductive reactance is 8 ohms, and the capacitive reactance is unknown. What value of reactance must the capacitor have in order for the total circuit impedance to be 13 ohms?

62. If, in a given ac series circuit, the resistance, inductive reactance, and capacitive reactance are of equal magnitude of 11 ohms, and the frequency is reduced to 0.411 of its value of resonance, what is the re-

sultant impedance of the circuit at the new frequency?

63. If an alternating voltage of 115 volts is connected across a parallel circuit made up of a resistance of 30 ohms, an inductive reactance of 17 ohms, and a capacitive reactance of 19 ohms, what is the total current drain from the source?

64. A parallel circuit is made up of five branches, three of the branches being pure resistances of 7, 11, and 14 ohms, respectively. The fourth branch has an inductive reactance value of 500 ohms. The fifth branch has a capacitive reactance of 900 ohms. What is the total impedance of this network? If a voltage is impressed across this parallel network, which branch will dissipate the greatest amount of heat?

65. In a parallel circuit composed of an inductance of 150 microhenries and a capacitance of 160 micromicrofarads, what is the resonant frequency?

66. What value of capacitance must be shunted across a coil having an inductance of 56 microhenries in order that the circuit resonates at 5000 kc?

67. What is the stage amplification obtained with a single triode operating with the following constants: Plate voltage 250, plate current 20 milliamperes, plate impedance 5000 ohms, load impedance 10,000 ohms, grid bias 4.5 volts, and amplification factor 24?

68. If a preamplifier, having a 600 ohm output, is connected to a microphone so that the power output is -40 db, and assuming the mixer system to have a loss of 10 db, what must be the voltage amplification necessary in the line amplifier in order to feed 10 db into the transmitter line?

69. If a certain audio frequency amplifier has an over-all gain of 40 db, and the output is 6 watts, what is the input?

70. What is the power output of an audio amplifier if the voltage across the load resistance of 500 ohms is 40 volts?

71. If a transformer, having a turns ratio of 1:10, working into a load impedance of 2000 ohms, and out of a circuit having an impedance of 15 ohms, what value of resistance may be connected across the load to effect an impedance match?

72. What is the formula for determining the db loss or gain.

73. What unit has been adopted by leading program transmission organizations as a volume unit and to what power is this unit equivalent?

74. If a frequency doubler stage has an input frequency of 1000-kc, and the plate inductance is 60 microhenries, what value of capacitance is necessary for resonance, neglecting stray capacitances?

75. The dc input power to the final amplifier stage is exactly 1500 volts and 700 milliamperes. The antenna resistance is 8.2 ohms and the antenna current is 9 amperes. What is the plate efficiency of the final amplifier?

76. How is the inverse peak voltage to which the tubes of a full-wave rectifier will be subject, determined from the known secondary voltages of the power transformer? Explain.

77. If a power transformer has a primary voltage of 4400 volts, a secondary voltage of 220 volts, and an efficiency of 98%, when delivering 23 amperes of secondary current, what is the value of primary current?

78. Three single phase transformers, each with a ratio of 220 to 2200 volts, are connected across a 220-volt, three phase line, primaries in delta. If the secondaries are connected in Y, what is the sec-

ondary line voltage?

79. What is the predominant ripple frequency in the output of the single phase fullwave rectifier when the primary source of power is 110 volts at 60 cycles?

80. If a power supply has a regulation of 11% when the output voltage at full-load is 240 volts, what is the output voltage at no load?

81. If a power supply has an output voltage of 140 volts at no load, and the regulation at full load is 15%, what is the output voltage at full load?

82. A rectifier filter power supply is designed to furnish 500 volts at 60 milliamperes to one circuit, and 400 volts at 40 milliamperes to another circuit. The bleeder current in the voltage divider is to be 15 milliampere. What value of resistance should be placed between the 500 and 400-volt taps of the voltage divider?

83. A 600-kc X-cut crystal, calibrated at 50° C, and having a temperature coefficient of -20 parts per million per degree, will oscillate at what frequency when its temperature is 60°C?

84. A certain transmitter has an output of 100 watts. The efficiency to the final, modulated amplifier stage is 50%. Assuming that the modulator has an efficiency of 66%, what plate input to the modulator is necessary for 100% modulation of this transmitter? Assume that the modulator output is sinusoidal.

85. If you decrease the percentage of modulation from 100% to 50% by what percentage have you decreased the power in the side-bands?

86. If the power output of a modulator is decreased from 1000 watts to 10 watts, how is the power expressed in db?

87. Given a Class C amplifier with a plate voltage of 1000 volts, and a plate current of 150 milliamperes which is to be modulated by a Class A amplifier with a plate voltage of 2000 volts, plate current of 200 milliamperes and a plate impedance of 15,000 ohms. What is the proper turns ratio for the coupling (modulation) transformer?

88. If the transmission line current of an FM broadcast transmitter is 8.5 ampere without modulation, what is the transmission line current when the percentage of modulation is 90%?

89. If the conductors in a two-wire radio frequency transmission line are replaced by larger conductors, how is the surge impedance affected, assuming no charge in the center to center spacing of the conductor?

90. The power input to a 72-ohm concentric transmission line is 5000 watts. What is the RMS voltage between the inner conductor and sheath?

91. The power input to a 72-ohm concentric line is 5000 watts. What is the current flowing in it?

92. An antenna is being fed by a properly terminated two-wire transmission line. The current in the line at the input end is 3 amperes. The surge impedance of the line is 500 ohms. How much power is being supplied to the line?

93. A long transmission line delivers 10kw into an antenna; at the transmitter end, the line current is 5 amperes and at the coupling house, it is 4.8 amperes. Assuming the line to be properly terminated, and the losses in the coupling system negligible, what is the power loss in the line?

94. A 50kw transmitter employs six tubes in push-pull parallel in the final Class B linear stage, operating with a 50kw output and an efficiency of 33%. Assuming that all the heat radiation is transferred to the water cooling system, what amount of

power must be dissipated from each tube?

95. If the daytime transmission line current of a 10-kw transmitter is 12 amperes, and the transmitter is required to reduce to 5-kw at sunset, what is the new value of transmission line current?

96. If the power output of a broadcast station is quadrupled what effect will this have upon the field intensity at a given point?

97. What is the frequency swing of an FM broadcast transmitter when modulated 60%?

98. If an FM transmitter employs one doubler, one tripler, and one quadrupler, what is the carrier frequency swing when the oscillator frequency swing is 2-kc?

99. An FM broadcast transmitter operating on 98.1 megacycles has a reactance tube modulated oscillator operating on a frequency of 4905-kc. What is the oscillator frequency swing when the transmitter is modulated 100% by a 2000-cycle tone?

100. An FM broadcast transmitter is modulated 50% by a 7000-cycle test tone. When the frequency of the test tone is changed to 5000 cycles and the percentage of modulation is unchanged, what is the transmitter frequency swing?

101. An FM broadcast transmitter is modulated 40% by a 5000-cycle test tone. When the percentage of modulation is doubled, what is the frequency swing of the transmitter?

102. What is the approximate speed of a 220-volt, 60-cycle, 4-pole, 3-phase induction motor?

103. What is the ohms per-volt of a voltmeter constructed of a zero-1 dc milliammeter and a suitable resistor which makes the full-scale reading of the meter 500 volts?

104. A current squared meter has a scale divided into 50 equal divisions. When 45 milliamperes flows through the meter, the deflection is 45 divisions. What is the current flowing through the meter when the scale deflection is 25 divisions?

105. If a heterodyne frequency meter, having a straight line relation between frequency and dial reading, has a dial reading of 31.7 for a frequency of 1390-kc, and a dial reading of 44.5 for a frequency of 1400-kc, what is the frequency of the ninth harmonic of the frequency corresponding to a scale reading of 41.2?

106. If a broadcast station receives a frequency measurement report indicating that the station frequency was 45 cycles low at a certain time, and the transmitter log for the same time, shows the measured frequency to be 5 cycles high, what is the error of the station frequency monitor?

107. If the two towers of a 950-kc directional antenna are separated by 120 electrical degrees, what is the tower separation in feet?

108. What must be the height of a vertical radiator one-half wavelength high if the operating frequency is 1100-kc?

109. If the vertical antenna is 405 feet high and is operated at 1250-kc, what is the physical height, expressed in wavelength?

110. If the field intensity of 25 millivolts per-meter develops 2.7 volts in a certain antenna, what is its effective height?

111. If the power output of a broadcast station has been increased so that the field intensity at a given point is doubled, what increase has taken place in antenna current?

112. If the day input power to a certain broadcast station antenna having a resistance of 20 ohms is 2000 watts, what would be the night input power if the antenna current were cut in half?

113. If the antenna current of a

station is 9.7 amperes for 5 kilowatts, what is the current necessary for a power of 1-kilowatt?

114. What is the antenna current when a transmitter is delivering 900 watts into an antenna having a resistance of 16 ohms?

115. The ammeter connected at the base of a Marconi Antenna has a certain reading. If this reading is increased 2.77 times, what is the increase in output power?

116. An FM broadcast transmitter has 370 watts plate power input to the last radio frequency stage and an antenna field gain of 1.3. The efficiency of the last radio frequency stage is 65% and the efficiency of the antenna transmission line is 75%. What is the effective radiated power?

117. What is the effective radiated power of a television broadcast station if the output of the transmitter is 1000 watts, the antenna transmission line loss is 50 watts and the antenna power gain is 3?

Answers

1. $E = IR$, $R = \frac{E}{I}$ and $I = \frac{E}{R}$

2. Using Ohm's Law, $R = \frac{E}{I}$, by substitution,

$$R = \frac{30}{5} = 6 \text{ ohms.}$$

3. Resistors in series add. Thus, $R_t = R_1 + R_2 + \text{etc.}$ Substituting the values given, $R_t = 10 + 5 = 15$ ohms (R_t = total resistance).

4. For two resistors connected in parallel, the total effective resistance can be determined by using the formula

$$R_t = \frac{R_1 R_2}{R_1 + R_2}$$

where R_t is the total effective resistance and R_1 and R_2 represent the individual resistors. Substituting the values given,

$$R_t = \frac{10 \times 15}{10 + 15} = \frac{150}{25} = 6 \text{ ohms}$$

5. $I = \frac{E}{R} = \frac{6}{300} = 0.02$ amp = 20 ma.

6. $E = IR = 0.05 \times 100 = 5$ volts.

7. When more than two resistors are connected in parallel, the following formula is used to determine the total effective resistance.

$$R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \text{etc.}}$$

Substituting the values given,

$$R_t = \frac{1}{\frac{1}{5} + \frac{1}{10} + \frac{1}{20}}$$

$$= \frac{1}{0.2 + 0.1 + 0.05}$$

$$= \frac{1}{0.35}$$

$$= 2.86 \text{ ohms}$$

This problem could also be solved by finding a lowest common denominator in the fractional denominator in the first step. Thus,

$$R_t = \frac{1}{\frac{1}{5} + \frac{1}{10} + \frac{1}{20}}$$

$$= \frac{1}{\frac{4}{20} + \frac{2}{20} + \frac{1}{20}}$$

$$= \frac{1}{\frac{7}{20}}$$

Then, inverting and multiplying,

$$R_t = \frac{1 \times 20}{7} = \frac{26}{7} = 2.86 \text{ ohms}$$

8. Because the battery is the 6-volt type, the resistor must "drop" the remaining 109 volts available from the line. (115-6) From Ohm's Law we have the simple relation that

$$R = \frac{E}{I}$$

By substituting the values from our problem in this formula, we obtain

$$R = \frac{109}{3}$$

$$= 36.3 \text{ ohms}$$

9. This problem is very similar to No. 8. The supply voltage is 6 volts and we need 5 volts. The resistor must, therefore, drop 1 volt. By Ohm's Law,

$$R = \frac{E}{I}$$

$$= \frac{1}{0.25}$$

$$= 4 \text{ ohms}$$

10. During normal operation, the voltage drop across the coil is

$$E = IR = 0.3 \times 600 = 180 \text{ volts}$$

Thus, the series resistor must drop 220 - 180 = 40 volts. Again, by simple Ohm's Law,

$$R = \frac{E}{I}$$

$$= \frac{40}{0.3}$$

$$= 133.3 \text{ ohms}$$

11. $P = EI \quad P = I^2R \quad P = \frac{E^2}{R}$

12. In this problem we are given I and R. Thus, we use the formula

$$\begin{aligned} P &= I^2R \\ &= (0.2)^2 \times 50 \\ &= 0.04 \times 50 \\ &= 2 \text{ watts} \end{aligned}$$

13. Returning to the basic formula $P = I^2R$, in this problem we know P and R. The job is to find the value of I.

If we divide both sides of the basic formula by R, we obtain,

$$\frac{P}{R} = I^2$$

Then, to find I, we must eliminate the square. We can do this by taking the square root of both sides of the equation. When this is done,

$$I = \sqrt{\frac{P}{R}}$$

since the square root of a square is the quantity itself. Substituting the values originally given,

$$I = \sqrt{\frac{200}{5000}}$$

$$= \sqrt{0.04}$$

$$= 0.2 \text{ ampere}$$

14. Each resistor is able to handle five watts without overheating. This dissipation capability is unaffected by the method of connection. The two resistors, either in series or parallel, can, therefore, dissipate a total of 10 watts.

15. The efficiency of any device is equal to the useful output power divided by the input power. The trans-

mitter efficiency in this problem is therefore,

$$\frac{300}{500} = 0.6, \text{ or } 60\%$$

16. (1) The quantity of electricity is given by the formula

$$Q = CE$$

where Q is in coulombs, C is in farads, and E is in volts. (2) The energy stored in a capacitor is expressed by the formula

$$W = \frac{1}{2}E^2C$$

where W is expressed in joules. One joule is defined as the energy expended in one second by an electric current of one ampere through a resistance of one ohm.

17. $C_t = C_1 + C_2 + C_3$, etc.

18. $C_t = \dfrac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \text{etc.}}$

19. $C_t = \dfrac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$

By substitution,

$$C_t = \frac{1}{\frac{1}{5} + \frac{1}{3} + \frac{1}{7}}$$

The LCD (lowest common denominator) for 5, 3, and 7 is 105. Thus,

$$C_t = \frac{1}{\frac{21}{105} + \frac{35}{105} + \frac{15}{105}}$$

$$= \frac{1}{\frac{71}{105}}$$

$$= \frac{105}{71}$$

$$= 1.48\ \mu f$$

20. $C_t = 10 + 20 + 30$
$= 60\ \mu f$

21. The formula Q = CE can be transposed to

$$E = \frac{Q}{C}$$

We can then see that when C is doubled, by the parallel connection, E is halved. The voltage across the two capacitors in parallel is, therefore, 58 volts.

22. $W = \frac{1}{2}LI^2$

where L = inductance in henries
I = current in amperes
W = energy in joules

23. $\lambda = \dfrac{300{,}000}{f}$ (kc)

where λ = wavelength in meters (Greek letter Lambda)

f = frequency

24. We must first determine frequency in cycles per second. The frequency is equal to the reciprocal of the period of one complete cycle. Thus,

$$f\ (\text{cps}) = \frac{1}{0.000001} = 1{,}000{,}000\ \text{cps}$$

Then, because 1,000,000 cps equals 1000 kc, we can use the formula previously given to find wavelength, that is,

$$\lambda = \frac{300{,}000}{1000} = 300\ \text{meters}$$

A more direct solution of the problem is to recall that electromagnetic waves travel 300,000,000 meters per second. In 0.000001 second, the wave must, therefore, travel

$$300{,}000{,}000 \times 0.000001 = 300 \text{ meters}$$

25. The effective (RMS) value of a sine wave is equal to 0.707 times the peak value. If the RMS value is applied to a resistance, it produces the same heating effect as an equal dc value.

26. A harmonic is defined as a multiple of the fundamental frequency, in this case, 360 kc. The 7th harmonic is, therefore, the 7th multiple of 360 kc,

$$7 \times 360 = 2520 \text{ kc}$$

27. The power factor can be determined when we know any of the following:

a. The ratio of true power (as measured by a wattmeter) to apparent power, as measured by a voltmeter and ammeter.

$$pf = \frac{P}{EI}$$

b. The ratio of resistance to impedance

$$pf = \frac{R}{Z}$$

c. The phase angle, Θ ($pf = \cos \Theta$)

d. The values of resistance and reactance. We then use these values to determine Z and then find the pf as in b.

28. When the reactance and resistance of a circuit are equal, the phase angle is 45°. If the reactance is greater than the resistance, the phase angle is some value between 45° and 90°. If the reactance is less than the resistance, the phase angle is some value between 0° and 45°.

29. $I = \frac{E}{Z} \quad Z = \frac{E}{I} \quad E = IZ$

where Z = circuit impedance in ohms.

30. The formula for determining inductive reactance X_L in ohms is

$$X_L = 2\pi fL$$

where 2π = a constant equal to approximately 6.28.

f = frequency in cycles per second

L = inductance in henries

Substituting the values given,

$$\begin{aligned} X_L &= 6.28 \times 5 \times 10^5 \times 6 \times 10^{-3} \\ &= 188.4 \times 10^2 \\ &= 18{,}840 \text{ ohms} \end{aligned}$$

31. The formula for finding capacitive reactance is

$$X_C = \frac{1}{2\pi fC}$$

where X_C = capacitive resistance in ohms

2π = a constant equal to approximately 6.28

f = frequency in cycles per second

C = capacitance in farads

Substituting the values,

$$\begin{aligned} X_C &= \frac{1}{6.28 \times 2 \times 10^{-8} \times 2 \times 10^4} \\ &= \frac{1}{25.12 \times 10^{-4}} \\ &= 398 \text{ ohms, approximately} \end{aligned}$$

32. The formula for determining

the voltage drop across the inductance is

$$E_L = IX_L$$

where E_L = voltage drop across inductance L

I = current in amperes through L

X_L = inductive reactance of L in ohms.

To use this formula, we must first determine circuit current. Because this is a series ac circuit the same current exists in all parts of the circuit and is equal to the ratio $E \div Z$. Impedance Z, in turn, is equal to

$$\begin{aligned} Z &= \sqrt{R^2 + (X_L - X_C)^2} \\ &= \sqrt{4^2 + (4 - 1)^2} \\ &= \sqrt{4^2 + 3^2} \\ &= \sqrt{16 + 9} \\ &= \sqrt{25} \\ &= 5 \text{ ohms} \end{aligned}$$

Then, $I = E \div Z = 50 \div 5 = 10$ amperes. Finally, we go back to the original formula given:

$$\begin{aligned} E_L &= IX_L \\ &= 10 \times 4 \\ &= 40 \text{ volts} \end{aligned}$$

33. In this case, Z is given by the basic relation $Z = E \div I$. Substituting given values in this equation:

$$Z = \frac{110}{0.3} = 367 \text{ ohms, approximately.}$$

34. $$f = \frac{1}{2\pi\sqrt{LC}}$$

where f = frequency in cycles per second

L = inductance in henries

C = capacitance in farads

35. The basic formula for impedance is $Z = \sqrt{R^2 + X^2}$. Obviously, if $X^2 = 0$, then $Z = R$, because the square root of a value squared is equal to the value itself. Thus, in the problem being considered, $Z = 6.5$ ohms, and by basic Ohm's Law, $I = E \div Z = 260 \div 6.5 = 40$ amperes. Then $E_L = IX_L = 40 \times 175 = 7000$ volts.

36. Because X_L and X_C are equal, the voltage drops developed across them cancel. Also, because we are dealing with a simple series circuit in which the sum of the voltage drops around the circuit is equal to the applied voltage, the entire 260 volts of applied emf must be dropped across the resistor.

37. The value of grid bias voltage is equal to

$$E_{CC} = IR_K$$

and,

$$R_K = E_{CC} \div I$$

where E_{CC} = desired grid bias voltage in volts

I = total current passing through cathode bias resistor in amps. R_K = resistance of cathode bias resistor in ohms.

Note: "I" may include plate and screen grid currents.

38. In this problem, notice that E_p and I_p are of no concern. The dc grid-bias voltage is determined entirely by grid current I_g and the value of the grid leak. Thus,

$$\begin{aligned} E_{CC} &= I_g R_g \\ &= 0.01 \times 5000 \\ &= 50 \text{ volts} \end{aligned}$$

39. The voltage regulation of a device is defined as the change in

voltage between full load and no load divided by the full-load voltage. To express regulation as a percentage regulation, as determined above, it is multiplied by 100. Thus, in our problem,

Percentage Regulation

$$= \left(\frac{126.5 - 115}{115}\right) 100$$

$$= \left(\frac{11.5}{115}\right) 100$$

$$= 0.1 \times 100$$

$$= 10\%$$

40. Assuming amplitude modulation is used, there will be the carrier frequency of 1500 kc and two sidebands, one 2 kc below the carrier and the other, 2 kc above the carrier. If FM is used, additional sidebands spaced at 2 kc intervals are also present. The number of such sidebands that need be considered depends on the modulation index.

41. Percentage modulation

$$= \left(\frac{E_{max} - E_{min}}{E_{max} + E_{min}}\right) 100$$

where E_{max} and E_{min} are the maximum and minimum values of the modulation envelope.

42. The first step is to determine the maximum permissible deviation from the assigned frequency,

$$0.0004 \times 2738 = 1.0952 \text{ kc}$$

Notice here that 0.04 percent is written as 0.0004 because percent means "by the hundred". Thus 0.04 means four hundredth parts of a quantity or number. The word "percent" or the symbol % thus does the job of two decimal places. The upper frequency limit is then

$$2738 + 1.0952 = 2739.0952 \text{ kc}$$

and the lower frequency limit is

$$2738 - 1.0952 = 2736.9048 \text{ kc}$$

43. The decibel is a unit used to express the ratio between two sound or electric power levels. The formula for calculating decibels (db) is

$$db = 10 \log_{10} \frac{P_1}{P_2}$$

where P_1 is generally the larger power. If amplification is involved, db becomes a plus (+) value, that is, simply db. If attenuation is involved, db is preceded by the negative (-) sign. Decibels can also be used to express the ratio between two voltages or two currents as follows:

$$db = 20 \log_{10} \frac{E_1}{E_2}$$

and

$$db = 20 \log_{10} \frac{I_1}{I_2}$$

In both of the above forms of the db equation, the two voltages or two currents involved must be measured at points of equal impedance.

In working with db in power problems, the following relations are useful to remember: an increase of 10 db increases power 10 times; an increase of 3db doubles the power, and a decrease of 3 db (-3 db) cuts power in half.

When working with voltages or currents, double the number of db involved to retain the same relationship. For example, an increase of 20 db increases E and I 10 times; an increase of 6 db doubles E and I; etc.

44. To have both the fundamental and harmonic field strength stated in the same units, we will first convert the signal strength, given in mv per meter, to µv per meter. This is accomplished simply by moving the decimal point three places to the right, so that 147 mv becomes 147,000 µv per meter. We now use the correct db formula using two voltages. Thus,

$$\text{db} = 20 \log_{10} \frac{147{,}000}{405}$$

$$= 20 \log_{10} 363$$

Because there are three places to the left of the decimal point, the characteristic for 363 is 2. From a table of logs we find the mantissa is 0.5599. Thus, the log of 363 is 2.5599, and

$$\begin{aligned}\text{db} &= 20\ (2.5599)\\ &= 51.2 \text{ approximately}\end{aligned}$$

If no log tables are available, we can estimate the answer from the relationships previously given. Multiplying 405 µv/m by 10 represents an increase of 20 db, and gives a value of 4050 µv/m. Multiplying again by ten gives us 40,500 µv/m and represents 40 db. If we double this value, it becomes 81,000 µv/m and represents 40 + 6 = 46 db. Doubling the voltage again gives a value of 162,000 µv/m and represents 46 + 6 = 52 db. This is somewhat higher than the 147,000 µv/m in our problem, but provides us with a reasonable estimate.

45. An image frequency lies as far above the oscillator frequency as the signal frequency does below the oscillator frequency. The difference between the desired signal and the oscillator frequency is called the "intermediate frequency." This intermediate frequency is equal to the difference between the image and oscillator frequencies. The image frequency is equal to the signal frequency plus twice the intermediate frequency.

In this problem, the i-f frequency is equal to 1300 - 1000 = 300 kc. The image frequency is then equal to 2(300) + 1000 = 1600 kc.

46. The watt hour is the unit used to measure work done in an electrical circuit. It is equal to the product of the circuit power in watts and time in hours. Thus, in this problem;

$$60 \times 20 = 1200 \text{ watt hours.}$$

This answer may also be expressed as 1.2 kilowatt hours.

47. By Ohm's Law, $I = E \div R$, where R is equal to the internal resistance of the battery plus the resistance of the light bulb. The resistance of the bulb is found by using the formula

$$\begin{aligned}R &= \frac{E^2}{P}\\ &= \frac{6^2}{3}\\ &= 12 \text{ ohms}\end{aligned}$$

The total resistance then is 12 + 0.01 = 12.01 ohms, and the circuit current is,

$$\begin{aligned}I &= E \div R\\ &= 6 \div 12.01\\ &= 0.4996 \text{ ampere or,}\end{aligned}$$

for practical purposes 0.5 ampere.

48. The number of poles and the frequency of the supply voltage. The speed in revolutions per minute is equal to 60 times the frequency di-

vided by the number of pairs of poles, that is

$$\text{rpm} = 60 \times f \div N$$

where N is the number of pairs of poles.

49. By Ohm's Law, the voltage drop is equal to IR. Thus,

$$E = IR = 0.0004 \times 25 = 0.01 \text{ volt}$$

Because the same voltage exists across all branches of a parallel circuit, the same 0.01 volt must act across the shunt so that the current through the shunt is,

$$I = E \div R = 0.01 \div 4 = 2.5 \text{ ma}$$

The unknown current value must, then, be the sum of the currents through the meter and through the shunt, that is,

$$0.4 + 2.5 = 2.9 \text{ ma}$$

50. The added value of resistance must be such that when 100 volts is applied across the meter, no more than 1 ma current passes through the meter. Thus,

$R = E \div I = 100 \div 0.001 = 100{,}000$ ohms.

51. The second harmonic is 1008 kc, the fundamental must be $1008 \div 2 = 504$ kc.

52. To find the error, which is proportional to frequency, we set up the following proportion:

$$\frac{10}{X} = \frac{600}{1110}$$

and by cross multiplication

$$600X = 11{,}110$$
$$X = 18.5 \text{ cps}$$

53. The basic formula that applies in this case is

$$L_t = L_1 + L_2 \pm 2M$$

where M is the mutual inductance, and L_1 and L_2 are the inductance of the two inductors. The formula indicates that if $M = 0$, then L_t is simply the sum of $L_1 + L_2$.

If the lines of force from one coil link the turns of the other, M is no longer zero, but assumes a definite value and must be considered in problems such as the above. If the fields aid each other, we use + 2M, and if the fields oppose each other, -2M.

54. The coefficient of coupling, designated k, is a measure of the degree of coupling between two circuits, and has a value ranging from 0 to 1. The two extremes indicate no coupling and maximum possible coupling, respectively. The formula for k is,

$$k = \frac{M}{\sqrt{L_1 L_2}}$$

when M is the mutual inductance in henries, L_1 and L_2 are the inductances of two coils in henries, and k is the coefficient of coupling, expressed as a pure number (dimensionless). Substituting the values given,

$$k = \frac{0.1}{\sqrt{0.2 \times 0.8}}$$
$$= \frac{0.1}{\sqrt{.16}}$$
$$= .1 \div .4$$
$$= 0.25$$

55. The mutual inductance between the two coils is found by simply transposing the formula given for k. This is accomplished by multiplying both sides of the equation by the square root of L_1 L_2. Thus,

$$M = k\sqrt{L_1 \; L_2}$$

Because k is given as unity (1), and L_1 is given as equal to L_2, the mutual inductance M is equal to the value of either L_1 or L_2. Thus, the total inductance is equal to four times the inductance of either coil. This can be seen in the equation

$$L_t = L_1 + L_2 + 2M$$

when M = L. Thus,

$$\begin{aligned} L_t &= L_1 + L_2 + 2L \\ &= 4L \end{aligned}$$

56. The phase angle is equal to the angle whose tangent is equal to $X \div R$. In the above problem the total reactance is $25 - 10 = 15$. Then the ratio $X \div R = 15 \div 15 = 1$. From a set of trigonometric tables, the angle is found to be 45°. Just remember, in any circuit where $X = R$, the phase angle is 45°. If the reactance is predominantly inductive, as in this problem, the 45° phase angle is said to be a "leading" phase angle. If capacitive reactance predominates, voltage lags current and the 45° phase angle is then "lagging". In either case, notice that "lead" or "lag" refers to the voltage in the circuit.

57. The reactance of a capacitor varies inversely with frequency; as frequency increases X_C decreases, and as frequency decreases, X_C increases. Thus, we can write,

$$\frac{600}{X} = \frac{1000}{800}$$

where $X = X_C$ at 1000 kc. Cross-multiplying,

$$\begin{aligned} 1000 \times &= (600 \times 800) \\ 1000 \times &= 480{,}000 \\ \times &= 480 \text{ ohms} \end{aligned}$$

58. The formula used in this solution of problems of this type is very similar to the formula for determining the impedance of an ac circuit. Mathematically,

$$E = E_R^2 + E_X^2$$

where E_X^2 is the algebraic sum of the voltages across the reactances. The voltage developed across the various elements are:

$$E_R = IR = 5 \times 12 = 60 \text{ volts}$$

$$E_L = IX_L = 5 \times 15 = 75 \text{ volts}$$

$$E_C = IX_C = 5 \times 40 = 200 \text{ volts}$$

Substituting these values in the previously given formula,

$$\begin{aligned} E &= (60)^2 + (200 - 75)^2 \\ &= (60)^2 + (125)^2 \\ &= 19{,}225 \\ &= 138.6 \text{ volts} \end{aligned}$$

59. Circuit current can only be determined after the lamp resistance and circuit impedance are known. The formula used for resistance is

$$R = \frac{E^2}{P} = \frac{(115)^2}{100} = 132.2 \text{ ohms}$$

This value is then used in the standard formula for impedance,

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$= \sqrt{(132.2)^2 + (355 - 130)^2}$$

$$= \sqrt{(132.2)^2 + (225)^2}$$

$$= \sqrt{17477 + 50625}$$

$$= \sqrt{68102}$$

$$= 261 \text{ ohms}$$

As a final step,

$$I = \frac{E}{Z} = \frac{220}{261} = 0.843 \text{ ampere}$$

60. Inductive reactance is directly proportional to frequency and capacitive reactance is inversely proportional to frequency. Therefore, X_L is doubled, and X_C is halved when the frequency is doubled. Under these conditions,

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$= \sqrt{(12)^2 + (14 - 3.5)^2}$$

$$= \sqrt{144 + 110.25}$$

$$= \sqrt{254.25}$$

$$= 15.9 \text{ ohms}$$

61. The standard formula for impedance is

$$Z = \sqrt{R^2 + X^2}$$

To find X, we first square both sides of the equation

$$Z^2 = R^2 + X^2$$

then subtract R^2 from both sides

$$Z^2 - R^2 = X^2$$

and finally take the square root of both sides

$$X = \sqrt{Z^2 - R^2}$$

where X = total circuit reactance.

Substituting the values given,

$$X = \sqrt{(13)^2 - (7)^2}$$

$$= \sqrt{169 - 49}$$

$$= \sqrt{120}$$

$$= 10.96 \text{ ohms}$$

The value of 10.96 ohms can represent either an inductive reactance (+) or a capacitive reactance (-), but we know we are looking for X_C so X is negative. Then, because

$$X = X_L - X_C = 10.96$$

and

$$= 8 - X_C$$

$$X_C = 18.96 \text{ ohms}$$

62. As noted before, X_L is directly proportional to frequency and X_C is inversely proportional to frequency. When the frequency (f) is reduced to 0.411 its value at resonance, therefore, is

$$X_L = 0.411 \times 11 = 4.52 \text{ ohms}$$

$$X_C = 11 \div 0.411 = 26.7 \text{ ohms}$$

and $Z = \sqrt{R^2 + (X_L - X_C)^2}$

$$= \sqrt{(11)^2 + (26.7 - 4.52)^2}$$

$$= \sqrt{(11)^2 + (22.2)^2}$$

$$= \sqrt{121 + 493}$$

$$= \sqrt{614}$$

$$= 24.8 \text{ ohms}$$

63. Because the same voltage acts across all branches of a parallel circuit

$$I_R = E \div R = 115 \div 30 = 3.83\text{A}$$

$$I_L = E \div X_L = 115 \div 17 = 6.76\text{A}$$

$$I_C = E \div X_C = 115 \div 19 = 6.05\text{A}$$

The total current drain is then equal to the vector sum of the branch currents, that is,

$$\begin{aligned} I_{total} &= \sqrt{I_R^2 + (I_L - I_C)^2} \\ &= \sqrt{(3.83)^2 + (6.76 - 6.05)^2} \\ &= \sqrt{15.27} \\ &= 3.91 \text{ amperes} \end{aligned}$$

64. If we assume an applied voltage of 100 volts,

$$I_1 = E \div R_1 = 100 \div 7 = 14.28 \text{ amps}$$

$$I_2 = E \div R_2 = 100 \div 11 = 9.09 \text{ amps}$$

$$I_3 = E \div R_3 = 100 \div 14 = 7.14 \text{ amps}$$

$$I_4 = E \div X_L = 100 \div 500 = 0.2 \text{ amps}$$

$$I_5 = E \div X_C = 100 \div 900 = 0.111 \text{ amp}$$

The currents through the three resistors are in phase and can be added directly. Thus,

$$\begin{aligned} I_R &= I_1 + I_2 + I_3 \\ &= 14.28 + 9.09 + 7.14 = 30.5 \text{ amps} \end{aligned}$$

Then, because $I_4 = I_L$ and $I_5 = I_C$,

$$\begin{aligned} I_{total} &= \sqrt{I_R^2 + (I_L - I_C)^2} \\ &= \sqrt{(30.5)^2 + (0.2 - 0.111)^2} \\ &= \sqrt{(30.5)^2 + (0.09)^2} \\ &= \sqrt{930 + .0081} \\ &= \sqrt{930} \\ &= 30.5 \text{ amperes} \end{aligned}$$

Knowing E and I, we can write

$$\begin{aligned} Z &= E \div I \\ &= 100 \div 30.5 \\ &= 3.28 \text{ ohms} \end{aligned}$$

Ideally, a capacitor or inductor dissipate no heat. The greatest heat is, therefore, dissipated in one of the resistive branches and is proportional to the power consumed, or to the product of EI. Because E is the same for all branches of a parallel circuit, I is the only value we need consider. The greatest current is in the 7-ohm resistor, and this branch must dissipate the most heat.

65. The resonant frequency of an LC circuit is found by using the formula

$$f = \frac{1}{2\pi\sqrt{LC}}$$

where 2π = constant, approximately 6.28. Thus, in the given problem,

$$\begin{aligned} f &= \frac{1}{6.28\sqrt{1.5 \times 10^{-4} \times 1.6 \times 10^{-10}}} \\ &= \frac{1}{6.28\sqrt{2.4 \times 10^{-14}}} \\ &= \frac{1}{6.28 \times 1.55 \times 10^{-7}} \\ &= \frac{1 \times 10^7}{9.73} \\ &= 1028 \text{ kc} \end{aligned}$$

66. To find the value of C, the formula used in problem 65 is transposed as follows:

First, squaring both sides to remove the radial sign,

$$f^2 = \frac{1}{(2\pi)^2 LC}$$

Then, multiplying both sides of the equation by C and dividing both sides by f^2,

$$C = \frac{1}{4\pi^2 Lf^2}$$

Substituting values given in the problem

$$C = \frac{1}{4(3.14)^2 \times 56 \times 10^{-6} \times (5 \times 10^6)^2}$$

$$= 18.1\ \mu\mu f$$

67. Stage amplification of a single triode is determined by using the formula

$$A = \frac{\mu R_L}{r_p + RL}$$

where A = stage gain

μ = amplification factor of triode

r_p = dynamic plate resistance of triode

R_L = plate load resistor

By substitution then,

$$A = \frac{2.4 \times 10^1 \times 1 \times 10^4}{5000 + 10{,}000}$$

$$= \frac{2.4 \times 10^5}{15{,}000}$$

$$= \frac{2.4 \times 10^5}{1.5 \times 10^4}$$

$$= \frac{2.4 \times 10^1}{1.5}$$

$$= 16$$

68. The total loss in db is

$$-40 + (-10) = -50 \text{ db}$$

Then, we can write

$$-50 + X = 10$$
$$X = 60$$

where X = required gain in db.

Using the basic formula for gain A,

$$db = 20 \log A$$

and substituting

$$60 = 20 \log A$$

$$\log A = \frac{60}{20}$$

$$\log A = 3$$
$$A = \text{antilog } 3$$

$$= 1000$$

69. The formula to use here is

$$db = 10 \log \frac{P_1}{P_2}$$

The output is, obviously P_1 and is, therefore, 6 watts. Thus, in our problem here we can write

$$40 = 10 \log \frac{6}{P_2}$$

$$\log \frac{6}{P_2} = \frac{40}{10}$$

$$\frac{6}{P_2} = \text{antilog } 4$$

$$\frac{6}{P_2} = 10{,}000$$

$$P_2 = \frac{6}{10{,}000}$$

$$= 0.0006 \text{ watts}$$

$$= 600\ \mu \text{ watts}$$

70. This problem is readily solved by using the formula

$$P = \frac{E^2}{R}$$

$$= \frac{40^2}{500}$$

$$= \frac{1600}{500}$$

$$= 3.2 \text{ watts}$$

71. A 15-ohm impedance is connected across the transformer primary. Using the formula

$$Z_S = Z_P \text{ (turns ratio)}^2$$

or

$$Z_S = Z_P \left(\frac{N_S}{N_P}\right)^2$$

where Z_S and Z_P = secondary and primary impedances, respectively, and N_P and N_S = number of primary and secondary turns, respectively, we first find the reflected impedance into the secondary.

$$Z_S = 15 \left(\frac{10}{1}\right)^2$$

$$= 15 \times 10^2$$

$$= 1500 \text{ ohms}$$

For a correct impedance match it is, therefore, necessary that $Z_S = 1500$ instead of 2000 ohms as given in the problem. Now we know that when two impedances are connected in parallel, the effective resistance R_E is equal to

$$R_E = \frac{R_1 R_2}{R_1 + R_2}$$

We already know R_E (1500 ohms) and R_1 (2000 ohms), so the problem is to find R_2. First, multiply both sides of the equation by $(R_1 + R_2)$,

$$R_E (R_1 + R_2) = R_1 R_2$$

Performing the indicated multiplication in the left side of the equation,

$$R_E R_1 + R_E R_2 = R_1 R_2$$

The quantity R_2 now appears on both sides of the equation, but we want it to appear only on one side, by itself, as the unknown. Thus, we must eliminate one of the R_2's. To do this, first subtract $R_E R_2$ from both sides of the equation so that

$$R_E R_1 = R_1 R_2 - R_E R_2$$

Next, factor R_2 in the right side of the equation,

$$R_E R_1 = R_2 (R_1 - R_E)$$

Then divide both sides by $R_1 - R_E$,

$$\frac{R_E R_1}{R_1 - R_E} = R_2$$

Substituting our known values

$$R_2 = \frac{1500 \quad (2000)}{2000 - 1500}$$

$$= \frac{(1.5 \times 10^3)(2 \times 10^3)}{500}$$

$$= \frac{3 \times 10^6}{5 \times 10^2}$$

$$= \frac{3 \times 10^4}{5}$$

$$= 0.6 \times 10^4$$

$$= 6000 \text{ ohms}$$

72. Power gain or loss

$$= 10 \log \frac{P_1}{P_2} \text{ db}$$

When voltages and currents are used in the equation, they must be measured at points of equal impedance and the numerical multiplier is 20 instead of 10.

Thus, voltage gain or loss

$$= 20 \log \frac{E_1}{E_2} \text{ db}$$

and, current gain or loss

$$= 20 \log \frac{I_1}{I_2} \text{ db}$$

73. The volume unit designated VU. The reference level, OVU, is 1 milliwatt in 600 ohms.

74. The formula for finding the resonant frequency f_r is,

$$f_r = \frac{1}{2\pi \sqrt{LC}}$$

and by transposition,

$$C = \frac{1}{4\pi^2 f_r^2 L}$$

Substituting given values,

$$C = \frac{1}{4 \times (3.14)^2 \times (2 \times 10^6)^2 \times 6 \times 10^{-6}}$$

$$= \frac{1}{4 \times 9.86 \times 4 \times 10^{12} \times 6 \times 10^{-5}}$$

$$= \frac{1}{946.56 \times 10^7}$$

$$= \frac{1 \times 10^{-7}}{947}$$

$$= 106 \ \mu\mu\text{f}$$

75. Plate efficiency expressed as a percentage

$$\left(\frac{P_o}{P_i}\right) 100$$

where P_o and P_i = output and input power, respectively.

In turn, $P_o = I^2 R$

$$= 9^2 \times 8.2$$

$$= 664 \text{ watts}$$

and $P_i = EI$

$$= 1.5 \times 10^3 \times 7 \times 10^{-1}$$

$$= 10.5 \times 10^2$$

$$= 1050 \text{ watts}$$

Then, plate efficiency $= \frac{664}{1050} \times 100$

$$= 63.2 \text{ percent}$$

76. The inverse peak voltage across the nonconducting tube is the rms value (peak-to-peak ac voltage) of the entire secondary winding times 1.414, less the drop in the conducting tube.

If the drop across the tube is not specified in a problem, the answer is found by simply multiplying the rms voltage value by 1.414.

77. With 98 percent efficiency, the power output of the secondary is

$$P_o = \frac{220 \times 23}{0.98}$$

$$= 5163 \text{ watts}$$

The same power must be delivered to the primary. Knowing the values of P and E,

$$I = P \div E$$
$$= 5163 \div 4400$$
$$= 1.173 \text{ amperes}$$

78. The secondary line voltage of a delta-Y connected three-phase system is determined by using the formula

$$E_s = E_p \times \text{turns ratio} \times 1.732$$

The turns ratio is the same as the voltage ratio, that is, 10:1, or simply 10. By substitution

$$E_s = 220 \times 10 \times 1.732$$
$$= 3810 \text{ volts}$$

In a Y connection, the output voltage is obviously greater than the voltage across a single line because two windings are in series between any two of the three windings. However, the voltages induced between any of the two windings are not entirely in phase, and this is why we use the factor 1.732 as a multiplier in the above equation, rather than 2.

79. In a single-phase, full-wave rectifier, the lowest and most predominant ripple frequency in the output is twice the applied frequency. Thus, the predominant ripple frequency is 2 × 60 = 120 cycles.

80. The output voltage at no load is equal to the full-load voltage, plus 11 percent of the full-load voltage. Thus,

$$0.11 \times 240 = 26.4 \text{ volts}$$

and no load voltage

$$= 240 + 26.4$$
$$= 266.4 \text{ volts}$$

81. The no-load output voltage E_{NL} is 15 percent greater than the full-load output voltage E_{FL}. Thus, the no-load voltage is equal to 115 percent of the full-load voltage, or

$$E_{NL} = \frac{140}{1.15}$$

$$= 121.7 \text{ volts}$$

In finding E_{NL}, we can also use the formula

$$\text{Regulation } (R) = \frac{E_{NL} - E_{FL}}{E_{FL}}$$

By transposition

$$R\,E_{FL} = E_{NL} - E_{FL}$$

$$R\,E_{FL} + E_{FL} = E_{NL}$$

$$E_{FL}\,(R + 1) = E_{NL}$$

and $$E_{FL} = \frac{E_{NL}}{R + 1}$$

By substitution

$$E_{FL} = \frac{140}{0.15 + 1}$$

$$= \frac{140}{1.15}$$

$$= 121.7 \text{ volts}$$

82. Two currents are present in the resistor section of this question, the 15-ma bleeder current, and the 40-ma taken by the 400-volt circuit. Total current through the resistor is, therefore,

$$40 + 15 = 55 \text{ ma}$$

The voltage drop across the same resistor is

$$500 - 400 = 100 \text{ volts}$$

By Ohm's Law,

$$R = E + I$$
$$= 100 + .055$$
$$= 1{,}818 \text{ ohms}$$

83. The crystal frequency decreases 20 cycles for every megacycle-operating frequency and for every 1°C temperature increase. In this problem the operating frequency is 0.6 mc and temperature increases

10°C. The total decrease in crystal frequency is

$$-20 \times 0.6 \times 10 = -120 \text{ cycles}$$

The new operating frequency is

$$\begin{aligned} 600{,}000 - 120 &= 599{,}880 \text{ cycles} \\ &= 599.88 \text{ kc} \end{aligned}$$

The characteristics of the crystal in this case are sometimes written as $-20 \div 10^6 \div °\text{C}$.

84. It is stated that the efficiency of the final stage is 50 percent. The dc power input to the stage must, therefore, be two times the output, that is, $100 \div 0.5 = 200$ watts. Under conditions of 100 percent modulation, the modulator must supply power equal to 50 percent of the dc power input to the final, that is, $200 \div 2 = 100$ watts. Then, because the efficiency of the modulator is only 66 percent, its input power must be $100 \div 0.66 = 151.5$ watts.

85. Assuming sinusoidal modulation, the power in the sidebands varies as the ratio of sideband power at 100 percent modulation squared to sideband power at the reduced percentage of modulation squared. Taking the values given, the new sideband power is in the ratio of

$$\frac{(100)^2}{(50)^2} = \frac{10{,}000}{2500} = \frac{4}{1}$$

This means P_{SB} is now one quarter (25 percent) of its value at 100 percent modulation.

86. For this problem we use the formula

$$\text{db power loss} = 10 \log_{10} \frac{P_1}{P_2}$$

where $P_1 = 1000$ watts

and $P_2 = 10$ watts

$$\begin{aligned} \text{db} &= 10 \log_{10} \frac{1000}{10} \\ &= 10 \log_{10} 100 \\ &= 10 \times 2 \\ &= 20 \text{ db} \end{aligned}$$

87. When a triode of moderate μ is used as a Class A amplifier, the load impedance should be about twice the dynamic plate resistance of the tube for reasonable power output and acceptable distortion (about 5 percent).

Assuming this condition is satisfied, the load impedance in our problem should be $2 \times 15{,}000 = 30{,}000$ ohms. The load on the modulator tube is equal to the dc plate impedance of the Class C modulated rf amplifier, in this problem,

$$\begin{aligned} \text{load on modulator} &= \frac{E_b}{I_b} = \frac{1000}{0.15} \\ &= 6667 \text{ ohms} \end{aligned}$$

We now have two widely different impedances of 30,000 and 6667 ohms, which must be matched by the modulation transformer.

To obtain this match, the turns ratio of the matching transformer should be equal to the square root of the ratio of the Class C stage impedance to the Class A stage impedance. Thus, the correct turns ratio (T.R.) is,

$$\begin{aligned} \text{T.R.} &= \frac{30{,}000}{6667} \\ &= 4.5 \\ &= 2.12 : 1 \end{aligned}$$

that is, 2.12 to 1.

88. The power output of an FM transmitter remains constant with or without modulation. Thus, the transmission line current remains at 8.5 amperes.

89. The formula for computing surge impedance Z_o is

$$Z_o = 276 \log_{10} \frac{2D}{d}$$

where D is the center-to-center spacing of the conductors and d is the diameter of the conductors.

Examination of the formula indicates that if d is increased while D remains unchanged, Z_o must decrease.

90. Assuming the line is nonresonant, we take the formula

$$P = \frac{E^2}{R}$$

and transpose to

$$E_{rms} = \sqrt{PR}$$

Then, by substitution,

$$\begin{aligned} E_{rms} &= \sqrt{72 \times 5000} \\ &= \sqrt{360{,}000} \\ &= 600 \text{ volts} \end{aligned}$$

If we wanted the peak voltage, we would multiply this rms value by 1.414.

91. Taking the basic formula

$$P = I^2R$$

and

$$I = \sqrt{P + R}$$

Substituting given values,

$$\begin{aligned} I &= \sqrt{\frac{5000}{72}} \\ &= \sqrt{69.5} \\ &= 8.34 \text{ amperes} \end{aligned}$$

92. Here we use the basic formula $P = I^2R$

$$\begin{aligned} P &= 3^2 \times 500 \\ &= 9 \times 500 \\ &= 4500 \text{ watts} \end{aligned}$$

93. We must first determine line impedance, which is equal to the input antenna impedance, assuming proper line termination. We do this by transposing the basic formula $P = I^2R$, so that

$$R = \frac{P}{I^2}$$

Substituting given values,

$$R = \frac{10{,}000}{(4.8)^2} = 434 \text{ ohms}$$

Knowing the value of R, the input power is

$$\begin{aligned} P_i &= I^2R \\ &= 5^2 \times 434 \\ &= 25 \times 434 \\ &= 10{,}840 \text{ watts} \end{aligned}$$

Then the line power loss is equal to $P_i - P_o$, that is,

$$\begin{aligned} \text{line power loss} &= 10{,}840 - 10{,}000 \\ &= 840 \text{ watts} \end{aligned}$$

94. We must first find the total power input which is equal to the power output divided by efficiency. Thus,

$$P_i = \frac{50{,}000}{0.33}$$

$$= 151{,}515 \text{ watts}$$

The total power dissipation for all six tubes is equal to

$$P_i - P_o = 151{,}515 - 50{,}000 = 101{,}515$$

Finally, the power dissipated by a single tube is equal to the total power dissipation divided by 6, that is, $101{,}515 \div 6 = 16{,}919$ watts.

95. The power is proportional to the square of the current as shown in the basic formula $P = I^2R$. Thus we can write

$$\frac{P_1}{P_2} = \frac{I_1{}^2}{I_2{}^2}$$

and by transposition

$$I_2 = I_1\sqrt{\frac{P_2}{P_1}}$$

Substituting given values,

$$I_2 = 12\sqrt{\frac{5}{10}}$$

$$= 12\sqrt{0.5}$$

$$= 12 \times 0.707$$

$$= 8.48 \text{ amperes}$$

96. The field intensity varies as the square root of radiated power. If power is increased four times, then field intensity doubles because $\sqrt{4} = 2$.

97. By definition, 100 percent modulation of an FM transmitter occurs when the frequency swing is ± 75 kc. At 60 percent modulation, the frequency swing then becomes

$$0.6 \times \pm 75 = \pm 45 \text{ kc}$$

98. Using a doubler, tripler, and quadrupler, the oscillator swing is multiplied

$$2 \times 3 \times 4 = 24 \text{ times}$$

Thus, the carrier frequency swing is

$$2 \text{ kc} \times 24 = 48 \text{ kc}$$

99. If the oscillator frequency is 4905 kc and the operating frequency is 98.1 mc, the multiplication between the oscillator and the final rf stage is

$$\frac{98.1}{4.905} = 20$$

At 100 percent modulator the output frequency swing is ±75 kc. This means the oscillator frequency swing at 100 percent modulation must be

$$\frac{1}{20} \times 75 \text{ kc} = \pm 3.75 \text{ kc}$$

100. The frequency of the test tone is of no importance in this problem. Since, at 100 percent modulation the frequency swing is ±75 kc, at 50 percent modulation it becomes

$$\frac{75 \text{ kc}}{2} = \pm 37.5 \text{ kc}$$

101. The new frequency swing is 80 percent of that which occurs at 100 percent modulation, that is,

$$0.8 \times 75 \text{ kc} = \pm 60 \text{ kc}$$

102. The voltage and number of phases need not be considered in this problem. The synchronous speed is equal to,

synchronous speed

$$= \frac{\text{line frequency} \times 60}{\text{No. pairs of poles}}$$

and by substitution,

synchronous speed

$$= \frac{60 \times 60}{2} = 1800 \text{ rpm}$$

In a synchronous motor, the emf generated by the rotor must be exactly the correct amount to produce a current that, in turn, produces a torque equal to the combined resisting torque of the load and rotor losses. This characteristic requires that the running speed be somewhat less, about 2 to 3 percent in the motor described, than the synchronous speed. This difference in speed is called "slip." Thus, the running speed of the motor in this problem would be

$$1800 \times 0.98 = 1764 \text{ rpm}$$

for 2 percent slip and

$$1800 \times 0.97 = 1746 \text{ rpm}$$

for 3 percent slip.

103. Regardless of the full-scale meter reading, the ohms per volt of a meter is equal to the reciprocal of full-scale current. Thus, in this problem,

$$\text{ohms per volt} = \frac{1}{0.001}$$

$$= 1000$$

104. The needle deflection is proportional to the square of measured current even though the scale is linear (has equal division). This permits us to set up the proportion

$$\frac{D_1}{D_2} = \frac{I_1{}^2}{I_2{}^2}$$

where D_1 = deflection of 25 divisions
D_2 = deflection of 45 divisions
I_2 = current for deflection D_2
I_1 = unknown current

By substitution

$$\frac{25}{45} = \frac{I_1{}^2}{(45)^2}$$

$$I_1{}^2 = \frac{25 \times (45)^2}{45}$$

$$I_1{}^2 = 25 \times 45$$

and $I_1 = \sqrt{25 \times 45}$

$$I_1 = \sqrt{1125}$$
$$= 33.5 \text{ ma}$$

105. When the frequency is changed 10 kc, from 1390 to 1400 kc, the dial reading changes 44.5 - 31.7 = 12.8 divisions. When the scale reading is 41.2 it is 9.5 divisions higher than the reading at 1390 kc, (41.2 - 31.7 = 9.5). Because 12.8 divisions represents 10 kc,

$$\frac{9.5}{12.8} \times 10 = 7.421 \text{ kc}$$

and the frequency at a dial reading of 41.2 is

$$1390 + 7.421 = 1397.421 \text{ kc}$$

The ninth harmonic of this frequency is

$$9 \times 1397.421 = 12576.789 \text{ kc}$$

106. The error in the monitor is the sum of the low reading report and the high reading recorded in the log, that is, 45 + 5 = 50 cps.

107. If 360° represents one wave-

length, the towers are separated by 1/3 wavelength (360/120). Converting the frequency in kc to wavelengths in meters

$$\lambda = \frac{300,000}{950}$$

$$= 316 \text{ meters}$$

The tower separation in meters is then

$$\frac{316}{3} = 105.3$$

To convert meters to feet, we multiply by 3.28. Thus, the tower separation in feet is

$$3.28 \times 105.3 = 345.4 \text{ feet}$$

108. The wavelength in meters is

$$= \frac{300,000}{1100}$$

$$= 272.7 \text{ meters}$$

One half wavelength at 1100 kc is, therefore,

$$\frac{272.7}{2} = 136.35 \text{ meters}$$

Multiplying by 3.28 we obtain the height of the half-wave vertical radiator in feet

$$3.28 \times 136.35 = 447 \text{ feet}$$

109. Changing height in feet to meters, we obtain

$$\frac{405}{3.28} = 123.44 \text{ meters}$$

Then, changing frequency in kc to meters,

$$= \frac{300,000}{1250}$$

$$= 240 \text{ meters}$$

Finally the ratio of the two measurements in meters is

$$\frac{123.44}{240} = 0.514 \text{ wavelengths}$$

110. The effective height is equal to the ratio of the total voltage developed, to the voltage developed per meter, that is,

$$\frac{2.7}{0.025} = 108 \text{ meters}$$

Converting to feet,

$$108 \times 3.28 = 354 \text{ feet}$$

111. Field intensity is directly proportional to antenna current and is a measure of voltage. When field density doubles, so does antenna current.

112. We know that $P = I^2R$. Inspecting this formula, it is apparent that when R is constant, if we cut I in half, P is reduced to $\frac{1}{4}$ its former value. Thus, the right input power is

$$\frac{1}{4} \times 2000 = 500 \text{ watts}$$

113. Power is proportional to the square of current, so we can write

$$\frac{P_1}{P_2} = \frac{{I_1}^2}{{I_2}^2}$$

By substitution

$$\frac{1}{5} = \frac{{I_1}^2}{(9.7)^2}$$

and transposing

$$I_1 = \frac{9.7}{\sqrt{5}}$$

$$= 4.33 \text{ amperes}$$

114. Here, we use the formula

$$I^2 = P/R \quad \text{and} \quad I = \sqrt{P/R}$$

substituting

$$I = \sqrt{\frac{900}{16}} = \frac{30}{4} = 7.5 \text{ amperes}$$

115. Output power is proportional to the square of the current. In this problem the increase in current is 2.77 times. Output power is, therefore,

$$(2.77)^2 = 7.67$$

times as great as its previous value.

116. The power output of the last rf stage is 370 × 0.65 = 241 watts. The power reaching the antenna is 241 × 0.75 = 180.4 watts. (Twenty-five percent is dissipated on line).

The antenna power gain is equal to the square of the antenna field gain, that is, $(1.3)^2 = 1.69$. Then, the effective radiated power is

$$1.69 \times 180.4 = 305 \text{ watts}$$

117. The power reaching the antenna is

$$1000 - 50 = 950 \text{ watts}$$

With an antenna power gain of 3, the effective radiated power is

$$3 \times 950 = 2850 \text{ watts}$$

SHOULD YOU DEPEND ON LUCK?

Accident--chance--luck--have very little bearing upon the production of any great result or true success in life. Of course, there have been many discoveries and accomplishments which may seem to be the result of "luck."

For instance: Newton "discovered" the law of gravity by watching an apple fall from a tree. Galileo "invented" the telescope after hearing of a toy constructed by a spectacle-maker. Brown "invented" the suspension bridge after watching a spider throw its web.

But these discoveries and inventions were made by men trained to take advantage of what they observed. Thousands of untrained men had seen the same things and paid no attention.

The new discoveries in radio--television--electronics will be made by men trained to take advantage of what they observe.

J. M. Smith


nri

ACHIEVEMENT THROUGH ELECTRONICS

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FCC RULES AND REGULATIONS

REFERENCE TEXT C112X

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FCC RULES AND REGULATIONS

C112X

STUDY SCHEDULE

☐ 1. Introduction . . . . Pages 1 - 2
Recommendations on how and what to study in order to pass your FCC exam are discussed in this section.

☐ 2. Basic Law – Element I . . . . Pages 2 - 5
This section gives 28 questions and answers on Element I.

☐ 3. Basic Operating Practice – Element II . . . . Pages 5 - 20
Fifty four general questions and answers and 68 Maritime questions and answers are covered in this section.

☐ 4. Basic and Advanced Radiotelephone for Elements III and IV. Pages 20 - 30
Here you study 55 questions and answers on Elements III and IV.

☐ 5. Glossary – FCC Words and Phrases . . . . Pages 31 - 85

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FCC Rules and Regulations

Although your final goal is a first-class radiotelephone license, the job is made somewhat easier by first acquiring a third-class radiotelephone permit. To do this, you must pass Elements I and II, which are essentially non-technical and made up largely of laws and regulations. To qualify for broadcast station operation Element IX must be passed. Once you have this permit, you will not have to be re-examined on Elements I and II when you take the examination for a first-class license.

The minimum passing grade on any Element is 75%.

The examination for Element I consists of 20 multiple-choice type questions.

The examination for Element II also consists of 20 multiple-choice type questions. This examination covers practices and procedures generally followed or required in radiocommunications. Two separate tests are offered. One is general and is intended for all persons seeking work in non-marine stations. This includes land, mobile, and aircraft stations. The general questions and answers are from 2.1 to 2.54. Marine questions are preceded by the letter "M".

The third part of this lesson contains "Rules and Regulations" type questions such as might be encountered in Elements III and IV. The examination for Element III consists of 100 questions and for Element IV, 50 questions. It is recommended that you study these questions after completing the material in the regular lesson dealing with television. Certain of these questions provide necessary information about transmitter frequency tolerances, permissible operating powers, methods of measurement acceptable by the FCC, etc. This material is not given in the regular lesson. Just remember, it costs you one to five points to miss a question on any examination, whether it is of a technical nature or related to Rules and Regulations.

A companion book on Rules and Regulations, C111X, should be consulted for more detailed information on many of the questions asked. We recognize that reading material of this type can be extremely tiresome, but it is an important part of your training and a job that must be done if you are to pass your FCC exam. It might be a good idea to underline or otherwise mark information which you will want to study again.

Lesson C111X also contains information related to amateur and citizen's band communications. It is not a required part of your study, but should be looked over at least partially whenever you have the opportunity. It may be that you will be employed by an organization that does a great deal of maintenance work on such equipment and this knowledge will then prove useful.

When you have completed the final examination in your course and, just before you go to take the FCC exam, it is suggested that you restudy the Rules and Regulations information contained both in this lesson and in Lesson C111X. This type of material is the most likely to be forgotten and can often cause the most trouble in passing the exam. More than one man has "sat" for his ticket with good preparation on technical material only to find that he failed due to a lack of knowledge about Rules and Regulations. Just remember, they all count and you cannot afford to give any points away.

It should be apparent by now why we think it is best to get your third class permit first, even though this means an extra trip to the FCC office and may cause you considerable inconvenience.

Basic Law - - Element I

1.1 Where and how is an operator license or permit obtained?

Ans. Licenses and permits are issued by the Federal Communications Commission to those citizens of the United States who have been found qualified to receive them. Applicants for a license or permit must appear before an FCC field engineer at a designated examining point and successfully complete a written examination and show other qualifications as required for the type of license or permit desired.

1.2 Who may apply for an FCC license?

Ans. Generally any citizen or other national of the United States. (The FCC may waive nationality requirements provided the alien holds an aircraft pilot certificate issued by the FAA and public interest is served.)

1.3 What is the usual license term for radio operators?

Ans. Five years from date of issuance.

1.4 When a licensee qualifies for a higher grade of FCC license or permit, what happens to the lesser grade license?

Ans. It will be cancelled upon issuance of the new license.

1.5 When may a license be renewed?

Ans. Any time during the final year of the license term or during a 1-year period of grace after expiration date of the license to be renewed.

1.6 Must a person designated to operate a radiotelephone station post his operator's license or permit, and if so, where?

Ans. Yes. The original license of each station operator must be posted at the place where he is on duty, or kept in his possession in the manner specified in the rules governing the particular class of station concerned.

1.7 If a licensee is notified that he has violated an FCC rule or provision of Communications Act of 1934, what must he do?

Ans. He must send a written reply within 10 days to the office of the Commission originating the official notice. If unavoidable circumstances make it impossible within that time, the reply must be made at the earliest practicable date and a satisfactory explanation given of the delay. The answer must be complete in itself and not abbreviated by reference to other correspondence or answers to other notices. It must contain a statement of action taken to correct the condition or omission. If the notice relates to violations due to physical or electrical characteristics of the transmitting apparatus, the reply shall state what steps, if any, have been taken to prevent future violations. If any new equipment is to be installed, the date of order, the name of the manufacturer, and the promised delivery date must be stated. If this installation requires a construction permit, the application file number or other identification must be given to help locate the application. If the notice relates to lack of attention to, or improper operation of, the transmitter, the name and license number of the operator in charge must be given.

1.8 What are the grounds for suspension of operator licenses?

Ans. Upon proof sufficient to satisfy the Commission that the licensee has: (1) violated any provision of any act, treaty, or convention binding on the United States, which the FCC is authorized to administer, or any regulation made by the FCC under any such act, treaty, or convention; (2) failed to carry out a lawful order of the master or person lawfully in charge of the ship or aircraft on which he is employed; (3) wilfully damaged, or permitted to be damaged, radio apparatus or installation; (4) transmitted superfluous radiocommunications or communications containing profane and/or obscene language or meaning; (5) transmitted false or deceptive signals, or call letters, not assigned by proper authority; (6) wilfully or maliciously interfered with any other radiocommunications or signals; or (7) obtained or attempted to obtain, or helped another person obtain, or attempt to obtain, an operator's license by fraudulent means.

1.9 If a licensee receives a notice of suspension of his license, what must he do?

Ans. Within 15 days of receipt of notice, or as soon as possible thereafter with a satisfactory explanation of the delay he must send an application for hearing to the FCC. The suspension order is held in abeyance until the hearing is concluded. At that time the FCC will affirm, modify, or revoke the order of suspension.

1.10 What must a person do whose operator license or permit has been lost, mutilated, or destroyed?

Ans. Immediately notify the Commission. A properly prepared and sworn application for a duplicate should then be submitted to the office of issue. This application should include a statement of the circumstances involved in the loss of the original license. It must also include a statement that a reasonable search has been made for the lost license, and if it is later found, it will be returned for cancellation. Documentary evidence of service obtained under the original license, or a statement under oath or affirmation embodying that information, must also be submitted.

1.11 Is it permissible to operate pending receipt of a duplicate operator license or permit after application has been made for reissue?

Ans. Yes. The operator should post a signed copy of the application for duplicate or renewal in place of the original document.

1.12 Is the holder of a radiotelephone third-class permit authorized to make technical adjustments to the transmitter he operates?

Ans. Only under the immediate supervision of a person holding the proper class of license required for the equipment involved. The licensed man is responsible for the proper functioning of the station equipment.

1.13 Should a radio station that is required to be operated by a licensed radio operator be a licensed radio station?

Ans. Yes. Any such station should be licensed.

1.14 Are communications bearing upon distress situations subject to the secrecy provisions of law?

Ans. No. Distress communications are exempt from these provisions.

1.15 When may an operator divulge the contents of an intercepted message?

Ans. Whenever the contents of any radiocommunication broadcast, transmitted by amateurs or others, is for the use of the general public, or relating to ships in distress.

1.16 What are the penalties for violating a provision of the Communications Act of 1934?

Ans. Any person upon conviction shall be punished for such offense for which no penalty (other than a forfeiture) is provided in this Act by a fine of not more than $10,000 or by imprisonment for a term not exceeding one year or both. Subsequent convictions provide the same penalty except for imprisonment term of two years.

1.17 What are the penalties for violating a provision of the Rules and Regulations of the FCC?

Ans. Any person upon conviction shall, in addition to any other penalties provided by law be punished by a fine of not more than $500 for each and every day during which such offense occurs.

1.18 Does the government have authority to impose fines for failure to comply with the Rules and Regulations governing the use of radio on compulsorily equipped ships?

Ans. Yes. Any person who knowingly violates any international radio treaty or convention to which the United States is a party may, upon conviction, be fined not more than $500 for each and every day during which such violation occurs. International treaties and conventions require certain ships to be compulsorily equipped with radio, and regulate the requirements and use of this equipment.

1.19 What government agency inspects radio stations in the U. S.?

Ans. The Federal Communications Commission has authority to inspect all radio stations required to be licensed, to ascertain if station construction, installation, and operation meet the requirements of the Commission Rules and Regulations.

1.20 Who keeps the station logs?

Ans. The station employee (or contract operator) competent to do so and having knowledge of facts required.

1.21 Who corrects errors in the station logs?

Ans. The operator on duty or other person who made the error. All corrections must be approved by the person responsible for keeping the log.

1.22 How may errors in the station logs be corrected?

Ans. By striking out the erroneous portion, or by making a corrective explanation on the log or attachment to it.

1.23 Is it prohibited by law to transmit false or fraudulent signals of distress?

Ans. Yes. International convention and the Communications Act of 1934 forbid false distress signals.

1.24 Under what conditions may messages be rebroadcasted?

Ans. Only when authority is obtained from the originating station.

1.25 What messages and signals may not be transmitted?

Ans. Unnecessary, unidentified, superfluous, obscene, indecent, profane, false or deceptive messages and signals. Unassigned call letters or signals may not be transmitted.

1.26 May an operator deliberately interfere with any radiocommunication or signal?

Ans. No.

1.27 What is meant by "harmful interference"?

Ans. Any emission, radiation or induction which endangers the functioning of a radionavigation service or of other safety services, or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service.

1.28 What type of communication has top priority in the mobile service?

Ans. All distress communications including alarm signals and distress traffic.

Basic Operating Practice
Element II

2.1 If a radiotelephone operator desires to make a brief test of a transmitter, what would be a good choice of words to use in the test?

Ans. The official call sign of the testing station, then the word "testing" followed by the count "1, 2, 3, 4 . . ." or by test phrases or sentences not in conflict with normal operating signals. The test signals shall have a duration not exceeding 10 seconds.

2.2 Why is it important to avoid unnecessary calls by radiocommunications?

Ans. To help prevent interference, to allow others the opportunity to use the air waves, and to improve station operating efficiency.

2.3 Is it required that a person listen in on a channel before transmitting?

Ans. Yes. Failure to listen in on a channel before transmitting can cause serious interference and should be avoided.

2.4 Why is it desirable to listen in on a channel before transmitting?

Ans. To make sure that interference will not be caused in communications already in progress.

2.5 Why should a trial of the radiotelephone installation be made every day?

Ans. To insure that it is in proper operating condition, not only for normal use, but also for emergency use.

2.6 How can a radiotelephone installation be tested?

Ans. See Question 2.1. In testing a radiotelephone transmitter, the operator should clearly indicate that he is testing, and station identification must be given. Tests should be made as brief as possible.

2.7 Before placing the transmitter apparatus of a radio station in operation for a test, what precautions must be taken?

Ans. The radio operator shall ascertain by careful listening that the test emissions will not be likely to interfere with any other communications.

2.8 What is the correct form for transmitting a distress call by radiotelephone?

Ans. The correct form for transmitting a distress call by radiotelephone is: (1) announce the distress signal Mayday three times, and (2) the words, "this is," followed by the identification of the mobile station in distress, the whole repeated three times. This distress call, when sent by radiotelephony, is generally preceded by the signal ... - - - ... (SOS) produced by a whistle or other suitable means.

2.9 Why is it a good policy to be brief in radiotelephone conversation?

Ans. To aid in preventing interference and give others an opportunity to use the airwaves.

2.10 What may happen to the received signal when an operator has shouted into a microphone?

Ans. Shouting into the microphone overloads the audio amplifier and overmodulates the transmitter. This causes so much distortion the signals may become unintelligible at the receiving end. Also, the width of the radiated band is increased, possibly causing interference with other services. The operator should make every effort to train his voice for most effective radiocommunication. His voice should be loud enough to be distinctly heard by the receiving operator, but not so loud as to become distorted and difficult to understand. Normally the microphone is held 2 to 6 inches from the operator's lips.

2.11 How should a microphone be treated when used in noisy locations?

Ans. The operator cups his hands over the microphone to exclude extraneous noise.

2.12 Why should the operator use well-known words and phrases?

Ans. To insure accuracy and save time from undue repetition of words.

2.13 What is the operator's responsibility upon hearing the word "SECURITY" repeated three times?

Ans. The word "SECURITY" is the safety signal. Upon hearing it three times the operator must continue to listen on the frequency on which it is being transmitted until he is satisfied that the message is of no interest to him. In addition, he must not make any transmission likely to interfere with the message.

2.14 What must the operator do if he is told that he is interfering with a distress call?

Ans. He must discontinue the cause of interference at once. The distress call has absolute priority over all other transmissions. All stations that hear it must immediately cease any transmission capable of interfering with the distress traffic and must listen on the frequency used for the emission of the distress call.

2.15 What are the meanings of these words: clear, out, over, roger, words twice, repeat, and break?

Ans. "Clear" means the sending station has completed all messages for the receiving station and is ending its transmission. "Out" means "This conversation is ended and no response is expected." "Over" means "My transmission is ended, and I expect a response from you." "Roger" means "I have received all of your last transmission." "Words twice" means "Give every phrase twice." "Say again" means "Repeat." "Break" means a separation between portions of a message.

2.16 Can a radio operator always consider his conversation completely confidential and not heard by other persons?

Ans. No. Radio signals normally travel outward from the transmitter in all directions, and can easily be intercepted by unauthorized persons.

2.17 In calling a station, how many times does the calling station generally repeat the call sign or name of the called station in each calling transmission?

Ans. Generally, not more than three times, followed by the letters of the calling station not more than three times.

2.18 Would you listen on a shared channel before transmitting? Why?

Ans. Yes, to make sure that you do not interfere with communications in progress.

2.19 Under normal conditions would a transmission on a calling frequency be proper if the receiver for that frequency were inoperative?

Ans. No. Calls other than emergency calls should not be made until the receiver is repaired.

2.20 What is the difference between calling and working frequencies?

Ans. Calling frequencies are those used for initial contact of another station, or stations, for some particular purpose. Once initial contact is made, all stations concerned shift to another designated frequency, known as the working frequency, for completion of further communications. For example, in the ship service, an initial call may be made on 500 kc. After contact is made, operation may be shifted to 410 kc.

2.21 Why is the station's call sign transmitted?

Ans. To avoid unnecessary repetition of call letters or names, and to enable monitoring stations to clearly identify all calls.

2.22 Should a test of the transmitting equipment be made each day?

Ans. Yes. Regular tests may reveal defects which, if corrected immediately, may prevent delays when communications are necessary. If, however, the equipment is used during the day for regular communications purposes, its general operating condition is known, and special tests are unnecessary.

2.23 What precautions should be observed in testing a station on the air?

Ans. The operator should clearly indicate that he is testing. Tests should be as brief as possible. He should be certain that the test message will not interfere with other communications in progress at the same time.

2.24 Should messages bearing upon safety, including weather information, be given priority over business messages?

Ans. Yes. Communications preceded by the safety signal have priority over all communications except those related to distress and preceded by the urgency signal.

2.25 If a station is required by law to listen in on a calling of distress frequency, when may the listening be discontinued?

Ans. The listening may be discontinued whenever the station is being used for transmission on that channel, or for communication on other radio channels.

In the event a distress, urgent, or safety call is heard, the operator must continue to listen until it is evident that the distress, urgency, or safety message does not concern his station.

2.26 Why should radio transmitters be "off" when signals are not being transmitted?

Ans. The operator of a radiotelephone station should not press the push-to-talk button except when he intends to speak into the microphone. Radiation from a transmitter may cause interference even when voice is not transmitted.

2.27 Why is it beneficial for the transmitter radio station to be in constant readiness for making a call?

Ans. So that it is available as needed, either for routine or emergency use.

2.28 If a station is required to maintain effective listening on a distress frequency, why is it desirable for the equipment to return automatically to reception on the distress frequency immediately after completing use of the equipment on another frequency?

Ans. To eliminate the possibility of the operator forgetting to switch back to the distress frequency channel.

2.29 Why is rapid frequency change of the transmitter and receiver desirable?

Ans. To permit the operator to quickly shift from a calling to a working frequency.

2.30 What would you do if you were told that your voice was distorting?

Ans. Lower my voice to see if the distortion is eliminated. If not, check the transmitter for improper operation.

2.31 Under what conditions may a station employ a calling frequency as contrasted to a working frequency?

Ans. When separate calling and working frequencies have been designated by the FCC, or by international convention, for the particular service involved.

2.32 Should a calling station repeat the call sign or name of the called station in each calling transmission more than three times?

Ans. No. Repetition of the call sign or name more than three times during any one calling is prohibited. The call may be repeated, however, after a one minute delay, if no response is obtained to the first call.

2.33 Why should stations using a shared frequency have an interval between calls?

Ans. To allow other stations sharing the frequency an opportunity to make calls.

2.34 Under what conditions may it be desirable to repeat important words?

Ans. When conditions of reception are such that words are not clearly intelligible, or when requested by the receiving operator.

2.35 What is the operator's responsibility upon hearing a distress call in a mobile service?

Ans. Cease all transmissions and continue to listen until he is certain the distress message in no way concerns his station.

2.36 Is it good practice to listen on the working frequency to be later used before making an initial call on the calling frequency?

Ans. Yes, to make sure that the desired communication can be handled on the working frequency. Unnecessary interference to other parties wishing to use the calling frequency is thereby avoided.

2.37 Why is it important to avoid unnecessary calls?

Ans. Unnecessary calls are forbidden by international law because they may cause interference with other stations wishing to use the air lanes.

2.38 State why station identification should be clearly made by a radio station.

Ans. To avoid unnecessary repetition of call letters or names, and to enable monitoring stations to identify all calls.

2.39 When routine radiocommunications are unreliable due to static or fading, should the operator continue transmitting or wait for more favorable conditions?

Ans. When radiocommunications at a station are unreliable or are disrupted due to static or fading, the operator should wait for more favorable conditions. Continued calling can cause severe interference with other stations.

2.40 What is the order of priority for communications?

Ans. (1) Distress calls, distress messages, and distress traffic; (2) communications preceded by an urgent signal; (3) communications preceded by the safety signal; (4) communications related to radio direction finding bearing; (5) communications related to the navigation and safe movement of aircraft; (6) communications related to the navigation, movements, and need of ships for an official meteorological service; (7) government communications for which priority rights have been claimed; (8) service communications related to the working of the radiocommunications service, or to communications previously transmitted; and (9) all other communications.

2.41 What is the priority of the urgency signal?

Ans. The urgency signal is second in the order of priority. Distress signals are first and safety signals third.

2.42 What are the distress, urgency, and safety signals?

Ans. The distress signal is the word MAYDAY. The urgency signal is the word PAN. The safety signal is the word SECURITY. All are repeated three times before the call.

2.43 In radiocommunications what does the transmission of the "distress," "urgency," and "safety" signals signify, respectively?

Ans. "MAYDAY" indicates that the ship, aircraft, or other vehicle sending the distress signals is threatened by serious and imminent danger, and requests immediate assistance. "PAN" indicates the calling station has an urgent message to transmit concerning the safety of a ship, aircraft, or other vehicle, or person on board or within sight. "SECURITY" indicates the station is about to transmit a message concerning the safety of navigation or important meterological warnings.

2.44 What information must be contained in a distress message?

Ans. (1) The distress call, (2) the name of the ship, aircraft, or vehicle in distress, (3) position of the latter, (4) the nature of the distress, (5) assistance, and (6) any other information which might facilitate matters.

2.45 Under what conditions may a mobile radio station send a distress message for another mobile station in distress?

Ans. (1) When the station in distress cannot itself transmit the message, (2) the master or person responsible for the ship, aircraft, or other vehicle carrying the station which intervenes believes additional help is needed, and (3) when directed to do so by the station in charge of distress traffic.

2.46 In the case of a mobile radio station in distress, what station is responsible for the control of distress message traffic?

Ans. The mobile station in distress, or the mobile station which, under the provision of the Commission Rules and Regulations, sends the distress call. These stations may, however, delegate the control of distress traffic to another station.

2.47 What does the distress call consist of?

Ans. The word MAYDAY repeated three times, and the words "this is," followed by the call of the mobile station in distress, repeated three times. The distress call may be preceded by the Morse Code signal ... --- ... (SOS) produced by a whistle or some other means.

2.48 What should an operator do when he leaves a transmitter unattended?

Ans. The transmitter should be left inoperable or inaccessible to unauthorized persons. The operator continues to bear responsibility for proper operation of the station.

2.49 Where does an operator find specifications for obstruction marking and lighting (where required) for the antenna towers of a particular radio station?

Ans. Part 17 of the Rules and Regulations of the FCC. If he wishes to determine the specifications for a particular station he should examine the station authorization issued by FCC.

2.50 What should an operator do if he hears profanity being used at his station?

Ans. He should discontinue broadcast immediately. Warn the offender. Take such other action as necessary to prevent recurrence. Prepare explanation in event suspension notice is received.

2.51 How does the licensed operator of a station normally exhibit his authority to operate the station?

Ans. By posting a valid operator license or permit at the transmitter control point.

2.52 When may an operator use his station without regard to certain provisions of his station license?

Ans. During a period of emergency in which normal communications facilities are disrupted as a result of hurricane, flood, earthquake or similar disaster.

2.53 Who bears the responsibility if an operator permits an unlicensed person to speak over his station?

Ans. The operator bears the responsibility for proper operation at all times.

2.54 What is meant by a "phonetic" alphabet in radiotelephone communications?

Ans. It is an alphabet or word list used to identify letters or words that may sound like other letters or words of different meaning. For example "group" may sound like "scoop," or "bridge" may sound like "ridge." It consists of 26 words, each word representing a letter of the alphabet. If the letters "GROUP" are represented in a phonetic alphabet as George, Roger, Oboe, Uncle and Peter, the word "group" is transmitted as "GROUP," G as in George, R as in Roger, O as in Oboe, U as in Uncle, P as in Peter.

MARITIME QUESTIONS AND ANSWERS

2.1M In making a ship-to-ship contact, except in an emergency involving safety, how long may a ship station continue calling in each instance?

Ans. Calling a particular station, either by voice or by automatic means, shall not continue for a period of more than 30 seconds.

2.2M Except in an emergency involving safety, if a ship radiotelephone station does not receive a reply after calling, how long must it wait before calling again?

Ans. At least two minutes.

2.3M What types of communications may be transmitted by ship stations on the ship-to-ship frequencies between 2000 and 3000 kc?

Ans. Frequencies between 2000 and 3000 kc can be used for distress, safety, or urgent signals, initial calls and answers, and normal radio traffic on working frequencies.

2.4M In regions of heavy traffic, how long may the ship-to-ship radiotelephone frequencies between 2000 and 3000 kc be used for any one exchange of communication (other than distress or emergency)?

Ans. Any one exchange shall not exceed three minutes in duration.

2.5M How is a ship radiotelephone station required to be identified in connection with its operation?

Ans. All radiotelephone emissions from a ship station shall be clearly identified by transmitting in the English language the official call sign assigned to that station by the Commission. If no call sign has been assigned the complete name of the ship and name of licensee shall be sent. The required station identification shall be made: (1) at the beginning and upon the completion of each transmission made for any other purpose, (2) at intervals not exceeding fifteen minutes whenever transmission is sustained for a period exceeding fifteen minutes.

2.6M Do public coast stations normally charge for forwarding messages reporting dangers to navigation?

Ans. No public coast station shall charge for the transmission, receipt, or reply of information concerning dangers to navigation originating on a ship of the United States or a foreign country.

2.7M How does the licensed operator of a ship radiotelephone station exhibit his authority to operate the station?

Ans. The operator must post his original license in a conspicuous place at the principal location on board ship at which the station is operated. If, however, the station is portable, or is a marine utility station, the operator can keep the required license, or a duly issued verification card attesting to the existence of the license, on his person.

2.8M If a radiotelephone installation is provided on board ship for safety purposes, in accordance with a treaty, and it becomes defective, what action must the licensed operator take?

Ans. The ship master must be notified promptly. If the ship is being navigated outside of port, the licensed operator shall make every effort to return the equipment to normal operating conditions as quickly as possible. If operating on the Great Lakes, and the equipment cannot be repaired sooner, it must be placed in operating condition at the next port of arrival. In addition, the master of the vessel must send a written report to the Federal Communications Commission in Washington, D. C., giving full particulars of the matter. The report must include the date the master became aware of the deficiency, a description of the steps taken to correct it, and a statement to the effect that the equipment has been, or will be, placed in operation before the ship again leaves port.

2.9M Who signs the radio log of a ship radiotelephone station certifying the entries made therein?

Ans. The licensed operator who is responsible for the operation of radiotelephone apparatus. The use of initials or signs in lieu of the operator's signature is not authorized.

2.10M What are the requirements for keeping watch on 2182 kc? If a radio operator is required to "stand watch" on international distress frequency, when may he stop listening?

Ans. Ship stations shall during its hours of service maintain an efficient watch for the reception of A3 and A3H emissions on 2182 kc frequency whenever such station is not being used for transmission on that frequency or for communication on other frequencies.

The watch period on an international distress frequency, when the ship station is in Region 1 or 3 shall be, insofar as possible, maintained at least twice each hour for 3 minutes commencing at X h.00 and X h.30, GMT.

2.11M Who may operate the radiotelephone set aboard the vessel?

Ans. Operation of all transmitting apparatus in any radio station in the maritime mobile service of the United States must normally be carried on only by a person holding an operator's license of the required class. However, at a ship station, the licensee or master may permit an unlicensed person to speak into the microphone.

2.12M Is it necessary for all vessels having knowledge of distress traffic to follow the traffic even if they do not take any part in it?

Ans. Any station of the mobile service having knowledge of distress traffic must follow such traffic, even if it does not take part in it. While following such distress traffic, however, if the mobile station is able to continue its normal service, it may do so, provided the distress traffic is well established, and provided it does not transmit on frequencies used for the distress traffic, and does not interfere with the distress traffic.

2.13M What is the proper form to use in acknowledging a distress message?

Ans. To acknowledge receipt of a distress message, use the following form: (1) call sign of the mobile station in distress repeated three times; (2) the letters DE in Morse Code or the words "This is," followed by (3) call sign of the station repeated three times; (4) the three-lettered group RRR in Morse Code, or the spoken word "received" repeated three times; and (5) distress signal.

2.14M What information is required to be sent following acknowledgement of a distress message?

Ans. The following information, in the order shown, must be transmitted as soon as possible by the mobile station acknowledging receipt: (1) its name, (2) its position, (3) the speed at which it is proceeding toward the ship, aircraft, or other vehicle in distress. Before sending the message, the station must insure that it will not interfere with the emissions of other stations better situated to render immediate assistance to the station in distress.

2.15M Is it necessary that the authority of the master or person responsible for the vessel be obtained prior to sending information required following acknowledgement of a distress call?

Ans. Yes. The information can only be sent on the order of the master or person responsible for the ship, aircraft, or other vehicle.

2.16M Is it desirable that care be taken to insure that an acknowledgment to a distress message will not interfere with other acknowledgments from vessels that are better able to assist?

Ans. Yes. Mobile stations that receive a distress message from another mobile station which, beyond any possible doubt, is not in their vicinity, must allow a short interval of time before acknowledging receipt of the message, to permit stations nearer the station in distress to answer and acknowledge receipt without interference.

2.17M Is a vessel which hears a distress message, but is not in a position to assist, required to take all steps to attract the attention of stations which might be in a position to assist?

Ans. Yes. Any mobile station not in a position to assist, after hearing a distress message which has not been properly acknowledged, must take all possible steps to attract the attention of mobile stations which are in a position to render assistance. For this purpose, with the approval of the person lawfully responsible for the station, the distress message may be repeated. All necessary steps are also taken to notify authorities who may be able to help.

2.18M Is it necessary to make a trial of the ship radiotelephone installation every day?

Ans. Yes, unless normal daily use of the equipment demonstrates that it is in proper operating condition for an emergency.

2.19M How can the radiotelephone installation be tested each day?

Ans. By making a test communication to demonstrate that the equipment is in proper operating condition for an emergency.

2.20M Does the Geneva 1959 Treaty give other countries the authority to inspect U. S. vessels?

Ans. Yes. The license must be produced for examination upon request of the government of the country being visited by the mobile station. The operator of the mobile station will cooperate in this examination.

2.21M What is the difference between calling and working frequencies?

Ans. Calling frequency is transmission from a station solely for getting the attention of another station(s) for a particular purpose. Working frequency is for all radiocommunications except calling.

2.22M How would you contact another vessel prior to communicating with it for routine communication purposes?

Ans. Example: Suppose Station KENT wishes to contact Station WASH. KENT would call as follows: "WASH, WASH, WASH, this is KENT, KENT, KENT, over." The repetition of the call station and the calling station as shown is not absolutely required and should never be repeated more than three times.

2.23M Why are call signs sent? Why should they be sent clearly and distinctly?

Ans. To enable other stations to identify calls easily.

2.24M In the mobile service, why

should messages be as brief as possible?

Ans. To allow other stations on the same frequency to make calls.

2.25M What procedure would you use in contacting the U. S. Coast Guard?

Ans. Example: "Baltimore Lifeboat Station, this is KENT, over."

2.26M Is it permissible to use 2182 kc for establishing contact prior to communicating on an appropriate public correspondence channel?

Ans. Yes; 2182 kc is the international radiotelephone calling frequency for the maritime mobile service.

2.27M Is it the general practice for a ship to use 2182 kc for establishing contact prior to communicating with a coast station on an appropriate public correspondence channel?

Ans. Yes.

2.28M Is it permissible to communicate with coast stations or any other stations on 2182 kc except for safety purposes?

Ans. Yes. See Question 2.26M.

2.29M Give a typical procedure you might use to call a vessel when its identity is not known.

Ans. In this case, the inquiry symbol CQ is used in place of the call sign of the station called. Example: "CQ, CQ, CQ, this is KENT, KENT, KENT, calling tanker at position 35 degrees north, 81 degrees west, over."

2.30M What do distress, safety and urgency signals indicate?

Ans. (1) Distress signal indicates that a mobile station is threatened by grave and imminent danger and requests immediate assistance. (2) Safety signal indicates that the station is about to transmit a message concerning the safety of navigation or giving meteorological warnings. (3) Urgency signal indicates that the calling station has a very urgent message to transmit concerning the safety of a ship, aircraft or other vehicle or the safety of a person.

2.31M What are the international urgency, safety and distress signals?

Ans. (1) Urgency signal is PAN. (2) Safety signal is SECURITY. (3) Distress signal is MAYDAY.

2.32M In the case of a mobile radio station in distress, what station is responsible for the control of distress message traffic?

Ans. It is the responsibility of the mobile station in distress or the station which had sent the message. These stations may delegate control to another station.

2.33M What daily attention should be given to the antenna tower lights at a radio station?

Ans. A daily check of the tower lights must be made not later than one hour after sunset. Inspection may be made either by visually observing the tower lights or by observing an automatic indicator, to insure that all tower lights are functioning properly as required.

2.34M What should be done in case of failure of the antenna tower lights at a radio station?

Ans. Report immediately by telephone or telegraph to the nearest airways communications station or office of the Federal Aviation Agency any observed failure of any code or rotating beacon light if such failure is not corrected within thirty minutes after observation thereof. Further, notify the above station or office immediately upon resumption of the required illumination. Data concerning the failure of tower lights must also be recorded in the station log. Include in the log entry the nature of the failure, the date and time the failure was observed, and the date, time, and nature of the adjustments, repairs, or replacements made. In the event of failure of rotating or beacon lights, the time of notifying the Federal Aviation Agency must also be entered.

2.35M How should a radio identification be made at a coast station using radiotelephony?

Ans. All radiotelephone emissions of a public coast station shall be clearly identified by voice transmission in the English language, either by the official call sign assigned to that station by the Commission or by the approximate geographic location of the station as approved in such case by the Commission. Alternatively, the official call sign may be clearly transmitted by tone-modulated telegraphy in the Morse Code, either by a duly licensed radiotelegraph operator or by means of an automatic device approved by the Commission.

2.36M If a licensed operator at the controls of a coast station observes or hears obscene language being transmitted through the facilities of a station, what action should be taken?

Ans. The station should immediately be removed from the air or steps taken to insure against further transmission of the obscene language. Details of the unlawful transmission must be entered in the station log, and a report sent to the FCC.

2.37M If a coast station hears a distress call from a mobile station, what action, if any, should the operator on duty take?

Ans. The operator must immediately cease any transmission capable of interfering with the distress traffic and listen on the frequency used for the emission of the distress call. After the distress message is sent, receipt should be acknowledged.

2.38M Under what circumstances should a public coast station employing radiotelephony use a calling frequency in establishing a communications circuit with a ship or aircraft?

Ans. (1) For distress signals and traffic, (2) urgency signals, and very urgent messages concerning safety of a ship, aircraft, or other vehicle, or safety of a person on board or within sight of such vehicles, (3) safety messages, (4) occasional messages of general interest to ship mobile stations, (5) normal calls, replies, and brief operating signals, (6) brief test signals, to determine if the station transmitting equipment is in good operating condition.

2.39M When may a coast station NOT charge for messages it is requested to handle?

Ans. Whenever tariffs for the requested service are not on file with the Commission. No charge will be made (1) for transmission of distress messages and replies thereto, involving safety of life and property at sea; (2) for transmission, receipt or relay of information about dangers to navigation, and (3) any services related to preparation for national defense.

2.40M In regions of heavy traffic why should an interval be left between radiotelephone calls? Why should a radio operator listen before transmitting on a shared channel?

Ans. Each authorized channel is available for use on a shared rather than an exclusive basis. Cooperation on use of assigned frequency reduces interference. Listen first, and if interference is likely, then wait until existing communication is ended. Intervals between calls permit calls to be made by another station using the same frequency.

2.41M How long may a radio operator in the mobile service continue attempting to contact a station which does not answer?

Ans. An interval of 2 minutes must elapse before calling a station again. After three attempts without response the interval will be 15 minutes. Should harmful interference to other communications not be indicated then the calls may be made as before, with a pause of 3 instead of 15 minutes. In all cases calling may continue for no longer than 30 seconds. These provisions do not apply to emergency calls involving safety.

2.42M What is meant by "safety communication" in the maritime service?

Ans. Safety communication is the transmission or reception of distress, alarm, urgent, or safety signals, or any form of radiocommunication which, if delayed in transmission or reception, may adversely affect the safety of life or property; an occasional test transmission or reception is necessary for determining if the radio equipment is in good working condition for purposes of safety.

2.43M Describe completely what actions should be taken by a radio operator who hears a safety message?

Ans. All stations hearing the safety signal shall listen to the safety message until they are satisfied that the message is of no concern to them. They shall not make any transmission likely to interfere with the message.

2.44M What are the requirements with respect to log-keeping at a coast station using radiotelephony?

Ans. Public coast stations using telephony shall maintain an accurate log during their hours of service. Each log sheet shall be numbered in sequence, be dated, and shall include the official call sign of the station and the signature of the licensed operator on duty. The entry "on duty," followed by his signature, shall be made by the operator at the beginning of a duty period. The entry "off duty," followed by his signature, shall be made by the operator ending a duty period. All log entries shall be currently completed and, unless otherwise stated, shall be made by the licensed operator on duty. The use of initials in lieu of any operator's signature is not authorized. The time of each entry shall be shown opposite the entry and, except for the following, shall be expressed in Greenwich Mean Time (GMT). (1) In the Great Lakes region, the time shall be expressed in Eastern Standard Time counted from 00:00 to 24:00 o'clock, beginning at midnight. (2) For public coast stations which communicate exclusively with vessels on inland waters of the United States, the time shall be expressed in local standard time. The first entry in each hour shall consist of four figures; additional entries in the same hour may be expressed in two figures by omitting the hour designation. The abbreviation GMT (or other kind used) shall be marked at the head of the column in which the time is entered.

2.45M What is the importance of the frequency 2182 kc?

Ans. This is the international distress frequency. It shall be used for this purpose by ship, aircraft and survival craft stations using frequencies in the authorized bands between 1605 and 4000 kc when requesting assistance from the maritime services.

2.46M What information must be contained in distress messages? What procedures should be followed by a radio operator in sending a distress message? What is a good choice of words to be used in sending a distress message?

Ans. The distress message consists of: (1) the distress signal MAYDAY; (2) name of mobile station in distress; (3) its position; (4) nature of distress; (5) kind of assistance desired; (6) any other information which might facilitate rescue.

The distress procedure consists of: (1) alarm signal (when possible); (2) distress call; (3) distress message. Transmissions shall be made slowly and distinctly with each word clearly pronounced to ease receipt of message. After sending the distress message, the mobile station may be requested to send suitable signs followed by its call sign or name to permit direction-finding stations to determine its position. As necessary, this request may be repeated at frequent intervals. The alarm signal, when possible, distress call and distress message shall be repeated at intervals until an answer is received. If no answer is received on the distress frequency, any other frequency may be used to attract attention.

2.47M Describe completely what actions should be taken by a radio operator who hears a distress message.

Ans. When a distress message is received from a mobile station which is, beyond any possible doubt, in his vicinity, he shall immediately acknowledge receipt. If reliable communication with one or more coast stations is practicable, ship stations may defer acknowledgment for a short interval so that a coast station may acknowledge receipt. When the distressed mobile station is, without doubt, not in the vicinity, then a short interval will be allowed to elapse before acknowledging receipt of message, in order to permit stations nearer the mobile station in distress to acknowledge receipt without interference.

Acknowledgment of receipt of a distress message takes this form: (1) Call sign or other identification of the station sending the distress message, spoken three times; (2) the words THIS IS; (3) call sign or other identification of the station acknowledging receipt, spoken three times; (4) the word RECEIVED; the distress signal MAYDAY.

Every mobile station which acknowledges receipt of a distress message shall, on the order of the master or person responsible for the ship, aircraft or other vehicle carrying such mobile station, transmit as soon as possible the following information in the order shown: (1) Its name; (2) its position; (3) the speed at which it is proceeding towards, and approximate time it will take to reach, the mobile station in distress.

Before acknowledging, the station shall ensure that it will not interfere with the emissions of other stations better situated to render immediate assistance to the station in distress.

2.48M Under what conditions may a coast station intervene in a distress situation?

Ans. Any station or mobile service, which is not in a position itself to render assistance, but which has heard a distress message that has not been acknowledged, must take all possible steps to attract the attention of stations which are in a position to render service. With the approval of the person lawfully in charge of the station, the distress call or the distress message may be repeated, using full power, on the distress frequency or on another frequency which may be used in case of distress.

2.49M To what extent may a coast station using radiotelephony communicate with stations other than ship stations?

Ans. Coast stations may communicate with other land stations to facilitate the transmission or reception of safety communications to and from a ship or aircraft station. They may also communicate with marine fixed stations on a frequency below 4000 kc, provided no harmful interference or intolerable delay is caused in communication with mobile stations as a result of such communication.

2.50M What is indicated by the use of the word "break" in a radiotelephone conversation?

Ans. The word "break" indicates a separation between portions of a message.

2.51M What is indicated by the use of the word "Roger" as a reply to a radiotelephone communication?

Ans. "Roger" means "I have received all of your last transmission."

2.52M What is indicated by the expression "words twice" when transmitted by radiotelephone?

Ans. "Words twice" is used to ask a station to send every phrase twice, or to inform a station every word will be sent twice.

2.53M What is indicated by the use of the words "read back" when transmitted by radiotelephone?

Ans. The words "read back" are used to request that the message be read back to the sending operator for verification.

2.54M Why are test transmissions sent? How often should they be sent? What is the proper way to send a test message? How often should the station's call sign be sent?

Ans. Tests may reveal defects or faults which, if corrected immediately, may prevent delays when communications are necessary. Before testing, listen to make sure there will be no interference with transmissions in progress. The call sign of the testing station, followed by the word "test" shall be announced on the radio channel being used for the test, as a warning that test emissions are about to be made on that frequency. The test must be delayed if there is interference or when "wait" is heard.

The operator announces the word "Testing" followed by "1, 2, 3, 4 ..." or by test phrases, sentences or test signals not in conflict with normal operating signals. The signals shall not last longer than 10 seconds. At the end of the test, announcement is made of the call sign, name of ship and its general location at time of test. One minute should elapse before retest on 2182 kc in heavy traffic, 5 minutes is waiting period. The call sign is sent at the beginning and end of test.

2.55M For what purpose is the frequency 121.5 megacycles authorized to be used by an aircraft radio station?

Ans. This is a universal simplex emergency and distress frequency for air-ground communications.

2.56M In lieu of using a call sign, how may a private aircraft telephone station be identified in the course of operation?

Ans. By use of the official aircraft registration number. The full number must be given for the initial call of a continuous series of communications or, name of owner of aircraft followed by last two characters of registration; type of aircraft may be substituted for name or owner, provided practice is initiated by ground station operator.

2.57M What types of communications or messages is an aircraft radiotelephone station authorized to transmit?

Ans. Communications limited to those necessary for safe aircraft operations.

2.58M When must an aircraft radio station and maintenance record be made available for inspection?

Ans. Upon request of an authorized representative of the FCC made to the licensee or his representative.

2.59M How is the communications range of an aircraft radio station at a very high frequency dependent upon the altitude of the aircraft?

Ans. The higher the aircraft, the greater the communications range, because very high frequency radiations travel in essentially straight lines, which limits reception to the line-of-sight distance. The higher the aircraft radio station, the greater the distance to the horizon and the greater the communications range.

2.60M Why should an aircraft station avoid making unnecessary "on the air" tests?

Ans. To avoid interference with communications in progress and to permit other stations with necessary business to use the airways.

2.61M What is the normal calling procedure of a private aircraft for contacting a control tower?

Ans. Example: "Washington control tower, this is Beechcraft N123456, Over."

2.62M How should an air carrier aircraft radiotelephone station normally be identified in operation in lieu of using the call sign?

Ans. The official aircraft registration number or company flight identification may be used, provided proper records are kept to permit ready identification of a given aircraft.

2.63M What is meant by a phonetic alphabet in radiotelephone communications?

Ans. A phonetic alphabet is a word list with each letter represented by an easily understood word. This alphabet is used to make sure a message is received correctly. For example, the word "robe" may be transmitted as Roger (r), oboe (o), baker (b), easy (e). The possibility of the word then being misunderstood is minimized.

2.64M What radio channel or channels are used by ships for communicating by radiotelephone with the U. S. Coast Guard?

Ans. Normally 2182 kc. In the Great Lakes, distress calls may be made on 2670 kc.

2.65M How often should station identification be made at a base or land radiotelephone station?

Ans. At the end of each transmission or exchange of transmissions, or once every 30 minutes of the operating period, as the licensee may prefer.

2.66M What entries must be made in the logs or records of radio stations required to have antenna tower lights?

Ans. The time each day the lights are turned on and off if manually controlled, the time a daily check for proper operation is made if an automatic alarm system is not provided, and results of periodic inspections required at least once every three months. This includes general condition of the system and any adjustments, replacements, or repairs made and the date.

If the tower lights fail, the log must show the nature of the failure, the time observed, the date, time, and nature of repairs, and the time the FAA was notified (for failures not corrected within 30 minutes). The results of the periodic inspection required every three months must be entered in the log, showing the date of the inspection and the condition of all tower lights and associated equipment. Any adjustments, replacements, or repairs to insure compliance with the lighting requirements must also be shown.

2.67M What attention should be given periodically to the antenna tower lights and associated apparatus at a radio station?

Ans. The lights must be checked at least once every 24 hours, either by direct observation or through a properly operating indicator system that will indicate any failure. Inspection must also be made at least once every three months to insure that all automatic or mechanical control devices, indicators, and alarm systems associated with the tower lighting is in proper operating order.

2.68M What precaution should be taken in a radio station which is left unattended in a public place?

Ans. The station should be locked up and other necessary precautions taken to prevent unauthorized use of the equipment. This may include temporary disablement of the equipment by tube removal, crystal removal, etc.

Basic and Advanced Radiotelephone for Elements III and IV

3.1 What is the frequency range associated with the following general subdivisions?

ULF	Below 30 kc	VHF	30-300 mc
LF	30-300 kc	UHF	300-3000 mc
MF	300-3000 kc	SHF	3-30 gc
HF	3-30 mc	EHF	30-300 gc

3.2 What is meant by the following emission designations? (Answer combined with question).

Symbol	Modulation	Type of transmission	Other characteristics
A3	**Amplitude**	**Telephony**	**Double sideband**
A3A	**Amplitude**	**Telephony**	**Single sideband, reduced carrier**
A5C	**Amplitude**	**Television**	**Vestigial sideband**
F3	**Frequency or phase**	**Telephony**	———
F5	**Frequency or phase**	**Television**	———
P3D	**Pulse**	**Telephony**	**Amplitude modulated**

3.3 What is the basic difference between type approval and type acceptance of transmitting equipment?

Ans. Type approval is based on tests made by FCC. Type acceptance is based on test data submitted by manufacturer or licensee and accepted by FCC.

3.4 May stations in the Public Safety Radio Services be operated for short periods of time without a station authorization issued by FCC?

Ans. No. Even in emergencies involving safety of life or property, authorization must be obtained.

3.5 What notification must be forwarded to the Engineer in Charge of the FCC district office prior to testing a new radio transmitter in the Public Safety Radio Service which has been obtained under a construction permit issued by FCC?

Ans. At least two days before test date, send written notice giving name of permittee, station location, call sign and frequencies to be used in testing.

3.6 Where may standard forms applicable to the Public Safety Radio Services be obtained?

Ans. From any engineering field office or FCC, Washington, D. C. 20554.

3.7 In general, what type of changes in authorized stations must be approved by FCC? What type does not require FCC approval?

Ans. Approval is necessary whenever any operation would be inconsistent with terms of authorization. Proposed changes which are consistent do not require approval.

3.8 The carrier frequency of a transmitter in the Public Safety Radio Service must be maintained within what percentage of the licensed value? Assume the station is operating at 160 mc with a licensed power of 50 watts.

Ans. .0005 per cent.

3.9 What is the authorized bandwidth and frequency deviation of Public Safety stations operating at about 30 mc? At about 160 mc?

Ans. At either 30 mc or 160 mc, authorized bandwidth is 20 kc with 5 kc frequency deviation.

3.10 What is the maximum percentage modulation allowed by FCC rules for stations in the Public Safety Radio Services which utilize amplitude modulation?

Ans. Not more than 100% on negative peaks.

3.11 Outline the transmitter measurements required by FCC rules for stations in the Public Safety Radio Service.

Ans. Each transmitter operating with a plate input power to the final radio frequency stage in excess of 3 watts must be measured at stated intervals. Objectives are to assure that (1) carrier frequency is maintained within prescribed tolerance, (2) maximum voltage specified in the station authorization is not exceeded, and (3) that modulation does not exceed specified limits.

3.12 What are the general requirements for transmitting the identification announcements for stations in the Public Safety Radio Service?

Ans. The assigned signal at each transmission, or each 30 minutes, as licensee prefers. Mobile units operating above 30 mc may use another identifier plus name of government unit.

3.13 When a radio operator makes transmitter measurements required by FCC rules for a station in the Public Safety Radio Service, what information should be transcribed into the station's records?

Ans. Results and dates of required measurements and name of person making measurements.

3.14 What are FCC general requirements regarding the records which are required to be kept by stations in the Public Safety Radio Service?

Ans. Kept in an orderly manner and in detail so that required facts are readily available. Key letters and abbreviations may be used provided meaning is set forth in the record. Each entry shall be signed by a qualified person who has actual knowledge of the recorded facts. No entries shall be erased, obliterated or destroyed within the retention period. Correction may be made by person originating the entry who shall strike out the erroneous portion, initial correction made and show date of correction. Records will be retained by licensee for at least one year.

3.15 If a standard broadcast station is licensed to operate at a frequency of 1260 kc, what are the minimum and maximum frequencies at which it may operate and still be within the proper limits established by the FCC rules?

Ans. The operating frequencies shall be maintained within 20 cycles. Therefore, 1259.98 kc and 1260.02 kc are frequency limits.

3.16 What is an STL system?

Ans. It is a fixed station using telephony for transmission of aural program material between the studio and the transmitter of a broadcasting station, other than an international broadcasting station, for simultaneous or delayed broadcast.

3.17 What is a proof-of-performance? How does a proof-of-performance differ from annual equipment performance measurements required by FCC rules? What must be included in the annual equipment performance measurements?

Ans. Proof-of-performance is a set schedule of tests made throughout the year for purposes of locating trouble areas, making measurements and keeping station at top efficiency. It is more inclusive and frequent than the annual measurements required by FCC. Required annual measurements are: (1) data and curves showing over-all audio frequency response from 30 to 7500 cps for approximately 25, 50, 85, and 100 (if obtainable) percent modulation; (2) data and curves showing audio frequency for harmonic content for 25, 50, 85, and 100 per cent modulation for fundamental frequencies of 50, 100, 400, 1000, 5000, and 7500 cps; (3) data showing percentage carrier shift for 25, 50, 85, and 100 per cent modulation with 400 cps tone; (4) carrier hum and extraneous noise generated within the equipment and measured as the level below 100 per cent modulation throughout the audio spectrum or by bands; and (5) measurements or evidence that spurious radiations including radio frequency harmonics are suppressed or are not causing objectionable interference.

3.18 What are the specifications of a plate current meter in the last radio stage of a transmitter?

Ans. Length of scale not less than 2.3 inches; accuracy at least 2% of full-scale reading; maximum rating shall not read off-scale during modulation; scale must have at least 40 divisions; full scale reading shall not be greater than five times the minimum normal indication.

3.19 Under what conditions may remote reading antenna ammeters be used to indicate antenna current?

Ans. When the transmission line current meter is used at transmitter.

3.20 (a) What is the maximum temperature variation at the normal operating temperature when using X or Y cut crystals? (b) When using low temperature coefficient crystals?

Ans. (a) Not greater than ± 0.1°C; (b) ± 1.0°C.

3.21 Who keeps the keys to the fence which surrounds the antenna base at a standard broadcast station? Where are the keys usually kept?

Ans. In possession of the operator on duty at the transmitter.

3.22 Changes to the broadcast transmitter of what general nature require FCC approval? What types of changes or alterations do not require approval?

Ans. No change in the last radio stage, the number of vacuum tubes, nor change to vacuum tubes of different power rating or class of operation, nor change in system or modulation without authority of the FCC. Other changes which do not affect the maximum power rating or operating power of the transmitter or the operation or precision of the frequency control equipment may be made at any time without authority of the FCC.

3.23 What is the FCC requirement regarding maintenance of operating power?

Ans. As practicable, but not above 5% nor below 10% of licensed power.

3.24 What is frequency tolerance at standard broadcast stations?

Ans. ± 20 cycles of assigned frequency.

3.25 What are the FCC requirements concerning stations which operate their transmitters by remote control?

Ans. Operation by remote control shall be subject to the following conditions: (1) the equipment at the operating and transmitting positions shall be so installed and protected that it is not accessible to or capable of operation by persons other than those duly authorized by the licensee; (2) the control circuits from the operating positions to the transmitter shall provide positive on and off control and shall be such that open circuits, short circuits, grounds or other line faults will not actuate the transmitter and any fault causing loss of such control will automatically place the transmitter in an inoperative position; (3) a malfunction of any part of the remote control equipment and associated line circuits resulting in improper control or inaccurate meter readings shall be cause for the immediate cessation of operation by remote control; (4) control and monitoring equipment shall be installed so as to allow the licensed operator at the remote control point to perform all the functions in a manner required by the FCC's rules; (5) the indications at the remote control point of the antenna current meter or, for directional antennas, the common point current meter and remote base current meters shall be read and entered in the operating log each half hour; (6) the indications at the transmitter, if a directional antenna station, of the common point current, base currents, phase monitor sample loop currents and phase indications shall be read and entered in the operating log once each day for each pattern. These readings must be made within two hours after the commencement of operation for each pattern.

All stations, whether operating by remote control or direct control, shall be equipped so as to be able to follow the prescribed procedure for Emergency Broadcast Service in event of national emergency.

3.26 At what place must the station license be posted? Where must the licenses of the operator be posted?

Ans. Station license: In a conspicuous place at the principal control point of the transmitter; a photocopy at each other control point is also required. Operator license: Original license or FCC Form 759 of each operator at his place of duty.

3.27 What are the operator requirements for AM broadcast stations?

Ans. Third Class permit with Broadcast Endorsement, provided that a First Class licensed operator is on call, except in the case of certain stations employing directional antennas, in which case a First Class operator must be on duty at all times during directional operation.

3.28 During what period of time preceding the date of filing for a renewal of the station license should such measurements be made?

Ans. During a four-month period before filing renewal applications.

3.29 (a) Explain how operating power is computed using direct measurement; (b) Using indirect measurement; (c) Under what conditions at a standard broadcast station may the indirect method be used?

Ans. (a) Resistance is determined by taking measurements at 5, 10, 15 and 20 kc on each side of operating frequency. These readings are plotted and a smooth curve developed. Where the operating frequency cuts the curve is the antenna resistance. Operating power is the square of the antenna current times the resistance. (b) Computed from the plate input power of the last radio stage and is the product of $E_p \times I_p \times F$. F is a factor based on method of modulation, maximum rated carrier power and class of amplifier. (c) Emergency, where antenna system has been damaged; pending completion of changes in antenna system or any change affecting antenna system.

3.30 What is the FCC requirement as to maintenance of percentage of modulation?

Ans. As high as possible along with good quality of transmission and broadcast practice. It must not exceed 100% on negative peaks of frequent recurrence, nor should it be less than 85% on peaks of frequent recurrence except as necessary to avoid objectionable loudness.

3.31 (a) What should be done if the station's modulation monitor becomes defective? (b) If the frequency monitor becomes defective?

Ans. (a) The station may be operated up to 60 days without FCC authority, pending repair or replacement. During this time modulation will be monitored with cathode ray oscilloscope, or other means. Engineer in Charge will be notified immediately of defect and whenever additional time is needed to correct. Entries in maintenance log showing date and time, when removed and restored to service; (b) same requirements as in (a) except frequency of station shall be measured by an external source at least each 7 days and results entered in maintenance log.

3.32 Under what conditions may a standard broadcast station use its facilities for communications directly with individuals or other stations? What notice shall be given when a station is operating during a local emergency?

Ans. When there is a severe emergency and communications are to dispatch aid, assist in rescue, promote safety of life and property, and reduce hardship. Notify the FCC in Washington, D. C., Engineer in Charge of District, of use to which station is being put, at the start and end of operations.

3.33 How many times and when must the station's operating log be signed by an operator who goes on duty at 10 a.m. and off duty at 6 p.m.?

Ans. Usually twice; upon going on and coming off duty.

3.34 (a) What entries shall be made in the operating log? (b) In the station's maintenance log?

Ans. (a) All readings pertaining to transmitting apparatus. (b) All readings, tests, and results of equipment installation and grounds inspections.

3.35 How long must the station's logs be kept?

Ans. Two years. However, logs with entries about a disaster, investigation by the FCC, will be kept until the FCC authorizes their destruction. Logs involving claims or complaints shall be kept until settled or when statute time limit runs out.

3.36 What information (logs and records) must be made available to an authorized FCC employee?

Ans. All logs, equipment performance records, copy of most recent antenna resistance or common-point impedance measurements submitted to the FCC and copy of most recent field intensity measurements to establish performance of directional antennas.

3.37 What specific equipment performance measurements must be made at all FM broadcast stations on an annual basis?

Ans. Audio frequency response, audio frequency harmonic distortion, output noise level (frequency modulation), and output noise level (amplitude modulation).

3.38 During what time period may an FM broadcast station transmit signals for testing and maintenance purposes?

Ans. Between 1:00 a.m. and 6:00 a.m.

3.39 What are the operator license requirements for FM broadcast stations?

Ans. One or more operators holding a Third Class permit, endorsed for broadcast operation (Element IX). However, a First Class licensed operator must be on call.

3.40 By what methods may operating power at FM broadcast stations be computed?

Ans. By direct or indirect method.

3.41 What is the allowable frequency tolerance at FM broadcast stations?

Ans. The center frequency shall be maintained within 2000 cycles of the assigned frequency.

3.42 What is SCA? What are some possible uses of SCA?

Ans. SCA means Subsidiary Communications Authorization. It permits limited types of secondary services on a multiplex basis. Possible uses are: (1) Transmissions of interest to segments of public wishing to subscribe thereto, and (2) transmissions of signals directly related to operation of FM broadcast stations.

3.43 What items must be included in an SCA operating log?

Ans. The times subcarrier generator is turned on and off; and times modulation is applied to, and removed from subcarrier. Daily entries are made excluding subcarrier interruptions of 5 minutes or less.

3.44 What are the transmission standards of subsidiary communications multiplex operations?

Ans. FM of SCA subcarriers shall be used; instantaneous frequency shall be within 20 to 75 kc -- range for stereophonic broadcast is 53 to 75 kc; sum of modulation of main carrier by SCA subcarriers shall not exceed 30% -- 10% for stereophonic broadcast; FM of main carrier caused by SCA subcarrier shall, in frequency range 50 to 15,000 cycles, be at least 60 db below 100% modulation.

3.45 What are the licensed operator requirements for a TV broadcast station? An FM broadcast station? A 5-kilowatt, nighttime directional standard broadcast station?

Ans. For a TV broadcast station, one or more licensed radiotelephone First Class operators must be on duty where the transmitting equipment is located, and in actual charge thereof when the equipment is in operation.

At an FM broadcast station, one or more operators holding a Third Class permit, endorsed for broadcast operation, must be on duty, provided that a First Class licensed operator is on call.

Adjustment of transmitting equipment by lower-class operators, except when under the immediate supervision of a radiotelephone First Class operator, shall be limited to the following; (1) putting the transmitter on and off the air in a routine manner; (2) making external adjustments required as a result of variations of primary power supply; (3) making external adjustments required to insure proper modulation.

Should the transmitting equipment be observed to be operating improperly, an operator holding a license other than First Class must shut down the equipment and call a radiotelephone First Class operator to make the necessary repairs and adjustments. Every FM station with power over 25 kw must have at least one

First Class licensed operator in full-time employment, whose primary duties are to insure proper equipment operation.

For an AM broadcast using a highly critical or unstable directional antenna, a First Class licensed operator is required on duty during directional operation. In less critical installations, a Third Class operator may be employed, but only if a First Class operator is on call.

3.46 What is the frequency tolerance for television stations?

Ans. (a) The carrier frequency of the visual transmitter shall be maintained within ± 1000 cycles of the authorized carrier frequency. (b) The center frequency of the aural transmitter shall be maintained 4.5 megacycles ± 1000 cycles, above the visual carrier frequency.

3.47 What items must be included in a television station's operating log? What items must be included in a television station's maintenance log?

Ans. The following entries shall be made in the operating log by the properly licensed operator in actual charge of the transmitting apparatus only: (a) An entry of the time the station begins to supply power to the antenna and the time it stops. (b) An entry of each interruption of the carrier wave, where restoration is not automatic, its cause and duration followed by the signature of the person restoring operation (if licensed operator other than the licensed operator on duty). (c) An entry, at the beginning of operation and at intervals not exceeding one-half hour, of the following (actual readings observed prior to making any adjustments to the equipment) and, when appropriate, an indication of corrections made to restore parameters to normal operating values: (1) Operating constants of last radio stage of aural transmitter (total plate voltage and plate current). (2) Transmission line meter readings for both transmitters. (d) Any other entries required by the instrument of authorization or the provisions of this part. (e) The entries required for tower light inspections.

The following entries shall be made in the maintenance log: (a) An entry each week of the time and result of test of auxiliary transmitters. (b) A notation each week of the calibration check of automatic recording devices. (c) An entry describing the method used and the results obtained in determining the operating frequency of the transmitter: (1) Whenever the required frequency check is made. (2) Whenever the required frequency measurement is made. (d) An entry of the date and time of removal from and restoration to service of any of the following equipment in the event it becomes defective: (1) Visual modulation monitoring equipment or aural modulation monitor. (2) Final stage plate voltmeters of aural and visual transmitters. (3) Final stage plate ammeters of aural and visual transmitters. (4) Visual and aural transmitter transmission line radio frequency voltage, current, or power meter. (e) Record of tower light inspections. (f) Entries shall be made so as to describe fully any operation for testing and maintenance purposes.

3.48 (a) How is operating power determined for the visual transmitter at a television broadcast station? (b) For the aural transmitter?

Ans. (a) Average power output shall be measured while operating into a dummy load of substantially zero reactance and a resistance equal to the transmission line characteristic impedance. During this measurement the transmitter shall be modulated only by a standard synchronizing signal with blanking level set at 75 per cent of peak amplitude as observed in an output monitor, and with this blanking level amplitude maintained throughout the time interval between synchronizing pulses. The peak power output shall be the power so measured in the dummy load multiplied by the factor 1.68. During this measurement the direct plate voltage and current of the last radio stage and the transmission line meter shall be read and compared with similar readings taken with the dummy load replaced by the antenna. These readings shall be in substantial agreement. (b) Determined by either the direct or indirect method: (1) Using the direct method, the power shall be measured at the output terminals of the transmitter while operating into a dummy load of substantially zero reactance and a resistance equal to the transmission line characteristic impedance. The transmitter shall be unmodulated during this measurement. During this measurement the direct plate voltage and current of the last radio stage and the transmission line meter shall be read and compared with similar readings taken with the dummy load replaced by the antenna. These readings shall be in substantial agreement. (2) Using the indirect method, the operating power is the product of the plate voltage (E_p) and the plate current (I_p) of the last radio stage, and an efficiency factor, F, as follows:

$$\text{Operating power} = E_p \times I_p \times F$$

3.49 Describe the Emergency Action Notification Attention Signal.

Ans. It consists of two 5-second carrier breaks and 15 seconds of 1000 cps tone. It is followed by the warning or other message.

3.50 Under normal conditions all standard FM and TV broadcast stations must make what provisions for receiving Emergency Action Notifications and Terminations?

Ans. Licensees are required to install, maintain, and operate radio receiving equipment for such messages.

3.51 What type of station identification shall be given during an Emergency Action Condition?

Ans. No broadcast of call letters; only State and Operational Area identifications will be given.

3.52 Must stations operate in accordance with Section 73.57 (about maintenance of operating power) of the FCC Rules during an Emergency Action Condition?

Ans. No, not while operating under NDEA.

3.53 How often and at what times must EBS tests be sent?

Ans. Once each week on an unscheduled basis between 8:30 a.m. and local sunset.

SPECIAL BROADCAST SERVICES

3.54 What is the uppermost power limitation imposed on remote pickup broadcast stations? STL (studio transmitter link) stations? Intercity relay broadcast stations?

Ans. Not more than 5% above the maximum authorized power for all these stations.

3.55 What records of operation must be maintained for each licensed remote pickup broadcast station?

Ans. Hours of operation; program transmitted; frequency check; remarks about transmission; entry giving points of program origination and receiver location; where an antenna structure(s) is required to be illuminated.

3.56 What is the basic difference between STL and Intercity Relay broadcast stations?

Ans. STL stations can transmit program material only between the studio and transmitter location of a broadcast station; the Intercity Relay station is authorized to transmit between broadcast stations.

3.57 What type of antenna must be used with STL and Intercity Relay broadcast stations?

Ans. Directional.

3.58 What is the frequency tolerance provided by FCC Rules for an STL (studio transmitter link) and Intercity Relay broadcast station?

Ans. ± 0.005 per cent of the assigned frequency.

ANTENNAS

3.59 Under what two general conditions must antenna structures be painted and lighted?

Ans. When higher than 200 feet above ground or when aeronautical study is required.

3.60 What color(s) should antenna structures be painted? Where can paint samples be obtained?

Ans. With alternate bands of aviation surface orange and white. Specifications for paint can be obtained from General Services Administration, Washington, D.C. 20407.

3.61 If a tower is required to be lighted and the lights are controlled by a light-sensitive device and the device malfunctions, when should the tower lights be on?

Ans. Sunset to sunrise.

3.62 As a general rule, a light-sensitive device used to control tower lights should face which direction?

Ans. North.

3.63 If the operation of a station's tower lights are not continuously monitored by an alarm device, how often should the lights be visually checked?

Ans. At least once each 24 hours.

3.64 How often should automatic control devices and alarm circuits associated with antenna tower lights be checked for proper operation?

Ans. Not less than once every three months.

3.65 What items regarding the operation of antenna tower lighting should be included in the station's maintenance log?

Ans. The licensee of any radio station which has an antenna structure requiring illumination shall make the following entries in the station record of the inspections: (a) The time the tower lights are turned on and off each day if manually controlled. (b) The time the daily check of proper operation of the tower lights was made, if automatic alarm system is not provided. (c) In the event of any observed or otherwise known extinguishment or improper functioning of a tower light: (1) Nature of such extinguishment or improper functioning. (2) Date and time the extinguishment or improper functioning was observed, or otherwise noted. (3) Date, time, and nature of the adjustments, repairs or replacements made. (4) Identification of Flight Service Station (Federal Aviation Administration) notified of the extinguishment of improper functioning of any code or rotating beacon light or top light not corrected within 30 minutes, and the date and time such notice was given. (5) Date and time notice was given to the Flight Service Station (Federal Aviation Administration) that the required illumination was resumed. (d) Upon completion of the periodic inspection required at least once each 3 months: (1) The date of the inspection and the condition of all tower lights and associated tower lighting control devices, indicators and alarm systems. (2) Any adjustments, replacements, or repairs made to insure compliance with the lighting requirements and the date such adjustments, replacements or repairs were made.

3.66 Generally speaking, how often should the antenna tower be painted?

Ans. As necessary to maintain good visibility.

3.67 Is it necessary to have replacement lamps for the station's antenna tower lights?

Ans. A sufficient supply of spare lamps shall be maintained for immediate replacement at all times.

3.68 Generally speaking, how soon, after a defect in the antenna tower lights is noted, should the defect be corrected?

Ans. As soon as possible.

3.69 What action should be taken if the tower lights at a station malfunction and cannot be repaired immediately?

Ans. Report immediately by telephone or telegraph to the nearest airways communications station or office of the Federal Aviation Agency any observed failure of any code or rotating beacon light if such failure is not corrected within thirty minutes after observation thereof. Further, notify the above station or office immediately upon resumption of the required illumination. Data concerning the failure of tower lights must also be recorded in the station log. Include in the log entry the nature of the failure, the date and time the failure was observed, and the date, time, and nature of the adjustments, repairs, or replacements made. In the event of failure of rotating or beacon lights, the time of notifying the Federal Aviation Agency must also be entered.

Glossary - - FCC Words and Phrases

CONTENTS

HOW TO USE THIS GLOSSARY

When the Service is shown separately, use the section first. Whenever the word or phrase is not shown, use Section I - General Definitions next.

These groupings by Service are arranged for your convenient reference when studying for the exam. Necessarily, all definitions are not shown because some of them are very simple or familiar.

An asterisk (*) with a word means an often asked definition in examination. Know these words very well.

I General Definitions

Active satellite. An earth satellite carrying a station intended to transmit or retransmit radiocommunication signals.

Alaska Communication System or ACS. The telecommunication system within Alaska and between Alaska and other areas which is operated by the United States Army Signal Corps.

Alaska-public fixed station. A fixed station in Alaska, which is open to public correspondence and is licensed by the Commission for radiocommunication between specified fixed points in Alaska exclusively.

Antenna power gain. The square of the ratio of the root-mean-square free space field intensity produced at one mile in the horizontal plane, in millivolts per meter for one kilowatt antenna input power to 137.6 mv/m. This ratio should be expressed in decibels (db). (If specified for a particular direction, antenna power gain is based on the field strength in that direction only.)

Antenna power input. The radio frequency peak or RMS power, as the case may be, supplied to the antenna from the antenna transmission line and its associated impedance matching network.

Antenna structures. The term "antenna structure" includes the radiating system, its supporting structures, and any surmounting appurtenances.

Assigned frequency. The frequency coinciding with the center of an authorized bandwidth of emission shall be specified as the assigned frequency.

Aural broadcast intercity relay station. A fixed station utilizing telephony for the transmission of aural program material between broadcasting stations other than international broadcasting stations, for simultaneous or delayed broadcast.

Aural broadcast STL (studio transmitter link) station. A fixed station utilizing telephony for the transmission of aural program material between a studio and the transmitter of a broadcasting station other than an international broadcasting station, for simultaneous or delayed broadcast.

***Authorized bandwidth.** The authorized bandwidth is the occupied bandwidth authorized to be used by a station.

Authorized carrier frequency. A specific carrier frequency authorized for use by a station, from which the actual or suppressed carrier frequency is permitted to deviate, solely because of frequency instability, by an amount not to exceed the frequency tolerance.

Authorized frequency. The frequency assigned to a station by the Commission and specified in the instrument of authorization.

Authorized power. The power assigned to a radio station by the Commission and specified in the instrument of authorization. The authorized power does not necessarily correspond to the power used by the Commission for purposes of its Master Frequency Record (MFR) and notification to the International Telecommunication Union.

***Bandwidth occupied by an emission.** The width of the frequency band (normally specified in kilocycles) containing those frequencies upon which a total of 99 percent of the radiated power appears, extended to include any discrete frequency upon which the power is at least 0.25 percent of the total radiated power.

Baseband. In the process of modulation, the baseband is the frequency band occupied by the aggregate of the modulating signals when first used to modulate a carrier.

***Base station.** A land station in the land mobile service carrying on a service with land mobile stations.

Broadcasting service. A radiocommunication service in which the transmissions are intended for direct reception by the general public. This service may include sound transmissions, television transmissions or other types of transmissions.

Broadcasting station. A station in the broadcasting service.

***Carrier.** In a frequency stabilized system, the sinusoidal component of a modulated wave whose frequency is independent of the modulating wave; or the output of a transmitter when the modulating wave is made zero; or a wave generated at a point in the transmitting system and subsequently modulated by the signal; or a wave generated locally at the receiving terminal which, when combined with the side bands in a suitable detector, produces the modulating wave.

***Carrier frequency.** The frequency of the carrier.

Carrier power. The average power supplied to the antenna transmission line by a transmitter during one radio frequency cycle under conditions of no modulation. This definition does not apply to pulse modulated emissions.

Citizens radio service. A radiocommunication service of fixed, land, and mobile stations intended for personal or business radiocommunications, radio signalling, control of remote objects or devices by means of radio, and other purposes not specifically prohibited.

***Coast station.** A land station in the maritime mobile service.

"Common carrier" or "carrier". "Common carrier" or "carrier" means any person engaged as a common carrier for hire, in interstate or foreign communication by wire or radio or in interstate or foreign radio transmission of energy, except where reference is made to common carriers not subject to the Communications Act of 1934, as amended; but a person engaged in radio broadcasting shall not, insofar as such person is so engaged, be deemed a common carrier.

Common carrier fixed station. A fixed station open to public correspondence.

Common carrier land station. A land station open to public correspondence.

Common carrier mobile station. A mobile station open to public correspondence.

Communication common carrier. Any person engaged in rendering communication service for hire to the public.

Communication-satellite earth station. An earth station in the communication-satellite service.

Communication-satellite service. A space service: (a) between earth stations, when using active or passive satellites for the exchange of communications of the fixed or mobile service, or (b) between an earth station and stations on active satellites for the exchange of communications of the mobile service, with a view to their re-transmission to or from stations in the mobile service.

Communication-satellite space station. A space station in the communication-satellite service, on an earth satellite.

Community antenna relay service. A fixed service, the stations of which are used for the transmission of television and related audio signals, and signals of standard and FM broadcasting stations, to a terminal point from which the signals are distributed to the public by cable.

Community antenna relay station. A fixed station in the community antenna relay service.

Control point. A control point is an operating position which is under the control and supervision of the licensee, at which a person immediately responsible for the proper operation of the transmitter is stationed, and at which adequate means are available to aurally monitor all transmissions and to render the transmitter inoperative.

Control station. A fixed station whose transmissions are used to control automatically the emissions or operations of another radio station at a specified location, or to transmit automatically to an alarm center telemetering information relative to the operation of such station.

Deep space. Space at distances from the earth equal to or greater than the distance between the earth and the moon.

Developmental broadcast station. A station licensed experimentally to carry on development and research primarily in radiotelephony for the advancement of the broadcast services.

Disaster communications service. A service of fixed, land, and mobile stations licensed or authorized to provide essential communications incident to or in connection with disaster or other incidents which involve loss of communications facilities normally available or which require the temporary establishment of communications facilities beyond those normally available.

Dispatch point. A dispatch point is any position from which messages may be transmitted under the supervision of the person at a control point.

Domestic fixed public service. A fixed service, the stations of which are open to public correspondence, for radiocommunications originating and terminating solely at points all of which lie within: (a) the State of Alaska, or (b) the State of Hawaii, or (c) the contiguous 48 states and the District of Columbia, or (d) a single possession of the United States. Generally, in cases where service is afforded on frequencies above 72 mc/s, radiocommunications between the contiguous 48 States (including the District of Columbia) and Canada or Mexico, or radiocommunications between the State of Alaska and Canada, are deemed to be in the domestic fixed public service.

Domestic fixed public station. A fixed station in the domestic fixed public service.

Domestic public radiocommunication services. The land mobile and domestic fixed public services the stations of which are open to public correspondence.

Duplex operation. Operating method in which transmission is possible simultaneously in both directions.

***Earth station.** A station in the space service located either on the earth's surface, including on board a ship, or on board an aircraft.

Environmental communications. Communications in the maritime mobile service for the broadcast of information pertaining to the environmental conditions, in which vessels operate, i.e., weather, sea conditions, time signals of a grade adequate for practical navigation, notices to mariners and hazards to navigation.

Experimental station. A station utilizing radio waves in experiments with a view to the development of science or technique. This definition does not include amateur stations.

Experimental television broadcast station. A station licensed for experimental transmission of transient visual images of moving or fixed objects for simultaneous reception and reproduction by the general public.

Facsimile. A system of telecommunication for the transmission of fixed images, with or without halftones, with a view to their reproduction in a permanent form.

Facsimile broadcasting station. A station licensed to transmit images of still objects for record reception by the general public.

Fixed earth station. An earth station intended to be used at a specified fixed point.

Fixed public control service. A fixed service carried on for the purpose of transmitting intelligence between transmitting or receiving stations in the public radiocommunication services and the message centers or control points associated therewith.

Fixed relay station. An operational fixed station established for the automatic retransmission of radiocommunications received from either one or more fixed stations or from a combination of fixed and mobile stations and directed to a specified location.

Fixed service. A service of radiocommunication between specified fixed points.

***Fixed station.** A station in the fixed service.

FM broadcasting station. A broadcasting station utilizing telephony by means of frequency modulation, and when authorized under a Subsidiary Communications Authorization (SCA), utilizing F9 emissions.

Frequency modulation (FM). A system of modulation where the instantaneous radio frequency varies in proportion to the instantaneous amplitude of the modulating signal (amplitude of modulating signal to be measured after pre-emphasis, if used) and the instantaneous radio frequency is independent of the frequency of the modulating signal.

Frequency tolerance. The extent to which an actual or suppressed carrier frequency is permitted to depart, solely because of frequency instability, from the authorized carrier frequency. The frequency tolerance is expressed in parts in 10^6 or in cycles per second.

Gc/s (gigacycle per second). A gigacycle per second (gc/s) means one thousand megacycles.

Great Lakes Agreement. The Agreement for the Promotion of Safety on the Great Lakes by Means of Radio and the regulations referred to therein, made by and between the Governments of the United States and Canada, which came into force on November 13, 1954.

***Harmful interference.** Any emission, radiation or induction which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service.

Hertz. A unit of frequency equivalent to one cycle per second. The terms Hertz (Hz) and cycle(s) per second (c/s) are synonymous and may be used interchangeably.

Hours of service. The period of time during each calendar day when a station is used, in conformity with the terms of the station authorization, for the rendition of its normal service.

Industrial radio services. Any service of radiocommunication essential to, operated by, and for the sole use of, those enterprises which for purposes of safety or other necessity require radiocommunication in order to function efficiently, the radio transmitting facilities of which are defined as fixed, land, mobile or radiolocation stations.

Industrial, scientific and medical equipment (ISM equipment). Devices which use radio waves for industrial, scientific, medical, or any other purposes including the transfer of energy by radio and which are neither used nor intended to be used for radiocommunication.

Instructional television fixed station. A fixed station operated by an educational organization and used primarily for the transmission of visual and aural instructional, cultural and other types of educational material to one or more fixed receiving locations.

ITFS response station. A fixed station operated at an authorized location to provide voice communication to an associated instructional television fixed station.

International broadcasting station. A broadcasting station employing frequencies allocated to the broadcasting service between 5950 kc/s and 26100 kc/s, whose transmissions are intended to be received directly by the general public in foreign countries.

International control station. A fixed station in the fixed public control service associated directly with the international fixed public radiocommunication service.

International fixed public radio service. A fixed service, the stations of which are open to public correspondence and which, in general, is intended to provide radiocommunication between any one of the contiguous 48 states (including the District of Columbia) and the State of Alaska, or the State of Hawaii, or any U. S. possession or any foreign point; or between any U. S. possession and any other point; or between the State of Alaska and any other point; or between the State of Hawaii and any other point. In addition, radiocommunications within the contiguous 48 states (including the District of Columbia) in connection with the relaying of international traffic between stations which provide the above service, are also deemed to be in the international fixed public radiocommunication service; provided, however, that communications solely between Alaska, or any one of the contiguous 48 states (including the District of Columbia), and either Canada or Mexico are not deemed to be in the international fixed public radiocommunication service when such radiocommunications are transmitted on frequencies above 72 mc/s.

International fixed public station. A fixed station in the international fixed public radio service.

International Radio Regulations. The Radio Regulations in force annexed to the International Telecommunication Convention, Geneva, 1959, as between the Government of the United States and other Contracting Governments; and such preceding international radio regulations as remain in force between the Government of the United States and other Contracting Governments.

Interzone station. A fixed station in the public safety (police) radio service using radiotelegraphy (A1 emission) for communication with zone stations within the zone and with interzone stations in other zones.

Ionospheric scatter. The propagation of radio waves by scattering as a result of irregularities or discontinuities in the ionization of the ionosphere.

Kc/s (kilocycle per second). A kilocycle per second (kc/s) means one thousand cycles per second.

***Land mobile service.** A mobile service between base stations and land mobile stations, or between land mobile stations.

Land mobile station. A mobile station in the land mobile service capable of surface movement within the geographical limits of a country or continent.

***Land station.** A station in the mobile service not intended to be used while in motion.

Land transportation radio service. Any private service of radiocommunication essential to the conduct of certain land transportation activities and operated for the use of persons engaged in those activities, the transmitting facilities of which are defined as fixed, land, mobile or radiolocation stations.

Loran station. A long distance radionavigation land station transmitting synchronized pulses. Hyperbolic lines of position are determined by the measurement of the difference in the time of arrival of these pulses.

Man-made structure. Any construction other than a tower, mast or pole.

Marine radiobeacon station. A radionavigation land station, the emissions of which are intended to enable a ship station to determine its bearing or its direction in relation to the marine radiobeacon station.

Maritime mobile service. A mobile service between coast stations and ship stations, or between ship stations, in which survival craft stations may also participate.

Maritime radionavigation service. A radionavigation service intended for the benefit of ships.

Mc/s (megacycle per second). A megacycle per second (mc/s) means one thousand kilocycles.

Mean power of radio transmitter. The power supplied to the antenna during normal operation, averaged over a time sufficiently long compared to the period corresponding to the lowest frequency encountered in actual modulation.

Meteorological aids service. A radiocommunication service used for meteorological, including hydrological, observations and exploration.

Meteorological-satellite earth station. An earth station in the meteorological-satellite service.

Meteorological-satellite service. A space service in which the results of meteorological observations, made by instruments on earth satellites, are transmitted to earth stations by space stations on these satellites.

Meteorological-satellite space station. A space station in the meteorological-satellite service, on an earth satellite.

Mobile earth station. An earth station intended to be used while in motion or during halts at unspecified points.

Mobile, except television pickup, station. Any mobile station other than a television pickup station.

Mobile relay station. A base station established for the automatic retransmission of mobile service communications which originate on the transmitting frequency of the mobile stations and which are retransmitted on the receiving frequency of the mobile stations.

***Mobile service.** A service of radiocommunication between mobile and land stations, or between mobile stations.

Mobile station. A station in the mobile service intended to be used while in motion or during halts at unspecified points.

Modulation. The process of producing a wave some characteristic of which varies as a function of the instantaneous value of another wave, called the modulating wave.

NARBA and the U.S./Mexican Agreement. "NARBA" means the North American Regional Broadcasting Agreement signed at Washington, D. C., November 15, 1950, which entered into force April 19, 1960 and to which the signatory countries are The Bahama Islands and Jamaica, Canada, Cuba, the Dominican Republic, and the United States of America. U.S./Mexican Agreement means the Agreement between the United States of America and the United Mexican States concerning radio broadcasting in the standard broadcast band signed at Mexico, D.F., January 29, 1957 which entered into force June 9, 1961.

Occupied Bandwidth. The frequency bandwidth such that, below its lower and above its upper frequency limits, the mean powers radiated are each equal to 0.5 percent of the total mean power radiated by a given emission.

Operational land station. A land station, excluding aeronautical stations, not open to public correspondence, operated by and for the sole use of those agencies operating their own radiocommunication facilities in the public safety, industrial, land transportation, marine or aviation services.

Operational mobile station. A mobile station, excluding aircraft stations, not open to public correspondence, operated by and for the sole use of those agencies operating their own communication facilities in the public safety, industrial, land transportation, marine or aviation services.

Passive satellite. An earth satellite intended to transmit radiocommunication signals by reflection.

Peak envelope power. The average power supplied to the antenna transmission line by a transmitter during one radio frequency cycle at the highest crest of the modulation envelope, taken under conditions of normal operation.

Peak power of a radio transmitter. The mean power supplied to the antenna during one radio frequency cycle at the highest crest of the modulation envelope, taken under conditions of normal operation.

Permittee. A person who holds a valid station construction permit.

Person. An individual, partnership, association, joint stock company, trust, or corporation.

Point of communication. This term, when applied to an Alaska-public fixed station, means a specified fixed station or specified geographic location with which such station is authorized to communicate.

Port operations. Communications in or near a port, or in locks or waterways, between coast stations and ship stations, or between ship stations, in which messages are restricted to those relating to the movement and safety of ships and, in emergency, to the safety of persons.

***Primary standard of frequency.** The primary standard of frequency for radio frequency measurements shall be the national standard of frequency maintained by the National Bureau of Standards, Department of Commerce, Washington, D. C. The operating frequency of all radio stations will be determined by comparison with this standard or the standard signals of station WWV of the National Bureau of Standards.

Public correspondence. Any telecommunication which the offices and stations must, by reason of their being at the disposal of the public, accept for transmission.

Public safety radio service. Any service of radiocommunication essential either to the discharge of non-Federal governmental functions or the alleviation of an emergency endangering life or property, the radio transmitting facilities of which are defined as fixed, land, mobile, or radiolocation stations.

Racon. A radionavigation system transmitting, automatically or in response to a predetermined received signal, a pulsed radio signal with specific characteristics.

Racon station. A radionavigation land station which employs a racon.

Radar. A radiodetermination system based on comparison of reference signals with radio signals reflected, or retransmitted, from the position to be determined.

Radio. A general term applied to the use of radio waves.

Radio astronomy. Astronomy based on the reception of radio waves of cosmic origin.

Radio astronomy service. A service involving the use of radio astronomy.

Radio astronomy station. A station in the radio astronomy service.

Radiobeacon station. A station in the radionavigation service, the emissions of which are intended to enable a mobile station to determine its bearing or direction in relation to the radiobeacon station.

Radiocommunication. Telecommunication by means of radio waves.

Radiodetermination. The determination of position, or the obtaining of information relating to position, by means of the propagation properties of radio waves.

Radiodetermination service. A service involving the use of radiodetermination.

Radiodetermination station. A station in the radiodetermination service.

Radio direction-finding. Radiodetermination using the reception of radio waves for the purpose of determining the direction of a station or object.

Radio direction-finding station. A radiodetermination station using radio direction-finding.

Radio district. The territory within each radio district.

Radiolocation. Radiodetermination used for purposes other than those of radionavigation.

Radiolocation land station. A station in the radiolocation service not intended to be used while in motion.

Radiolocation mobile station. A station in the radiolocation service intended to be used while in motion or during halts at unspecified points.

Radiolocation service. A radiodetermination service involving the use of radiolocation.

Radionavigation. Radiodetermination used for the purposes of navigation, including obstruction warning.

Radionavigation land station. A station in the radionavigation service not intended to be used while in motion.

Radionavigation mobile station. A station in the radionavigation service intended to be used while in motion or during halts at unspecified points.

Radionavigation-satellite earth station. An earth station in the radionavigation-satellite service.

Radionavigation-satellite service. A service using space stations on earth satellites for the purpose of radionavigation, including, in certain cases, transmission or re-transmission of supplementary information necessary for the operation of the radionavigation system.

Radionavigation-satellite space station. A space station in the radionavigation-satellite service, on an earth satellite.

Radionavigation service. A radiodetermination service involving the use of radionavigation.

Radionavigation station. A station in the radionavigation service.

Radio range station. A radionavigation land station in the aeronautical radionavigation service providing radial equisignal zones.

Radiosonde. An automatic radio transmitter in the meteorological aids service usually carried on an aircraft, free balloon, kite or parachute, and which transmits meteorological data.

Radio service. An administrative subdivision of the field of radiocommunication. In an engineering sense, the subdivisions may be made according to the method of operation, as, for example, mobile service and fixed service. In a regulatory sense, the subdivisions may be descriptive of particular groups of licensees.

Radio waves (or Hertzian waves). Electromagnetic waves of frequencies lower than 3,000 gc/s (3,000,000 mc/s), propagated in space without artificial guide.

Region 1, Region 2, and Region 3. Those geographic areas defined as "Region 1", "Region 2", and "Region 3" in Article 5 of the International Radio Regulations, Geneva, 1959.

Remote pickup broadcast base station. A base station licensed for communicating with remote pickup broadcast mobile stations.

Remote pickup broadcast mobile station. A land mobile station licensed for the transmission of program material and related communications from the scene of events which occur outside a studio to broadcasting station, and for communicating with other remote pickup broadcast base and mobile stations.

Repeater station. An operational fixed station established for the automatic retransmission of radio communications received from any station in the Mobile Service.

Safety Convention. The International Convention for the Safety of Life at Sea, London, 1960, including the Regulations annexed thereto.

Safety service. A radiocommunication service used permanently or temporarily for the safeguarding of human life and property.

Selective calling. A means of calling in which signals are transmitted in accordance with a prearranged code for the purpose of operating a particular automatic attention device in use at the selected station whose attention is sought.

Ship station. A mobile station in the maritime mobile service located on board a vessel, other than a survival craft, which is not permanently moored.

Ship station license. A license authorizing the operation of a ship station, a survival craft station associated with a ship, or a ship radionavigation station.

Signaling. Intermittent or periodic transmission (excluding radiotelephony or any type of Morse code) of intelligence by means of prearranged tones, impulses, or combinations thereof, designed to actuate a mechanism at the point of reception.

Simplex operation. Operating method in which transmission is made possible alternately in each direction, for example, by means of manual control.

Spacecraft. Any type of space vehicle including an earth satellite or a deep-space probe, whether manned or unmanned.

Space research earth station. An earth station in the space research service.

Space research service. A space service in which spacecraft or other objects in space are used for scientific or technological research purposes.

Space research space station. A space station in the space research service.

Space telecommand. The use of radiocommunication for the transmission of signals to a space station to initiate, modify or terminate functions of the equipment on a space object, including the space station.

Space telemetering. The use of telemetering for the transmission from a space station of results of measurements made in a spacecraft, including those relating to the functioning of the spacecraft.

Space tracking. Determination of the orbit, velocity or instantaneous position of an object in space by means of radio determination, excluding primary radar, for the purpose of following the movement of the object.

Space service. A radiocommunication service: (a) between earth stations and space stations, or (b) between space stations, or (c) between earth stations when the signals are retransmitted by space stations, or transmitted by reflection from objects in space, excluding reflection or scattering by the ionosphere or within the earth's atmosphere.

Spurious emission. Emission on a frequency or frequencies which are outside the necessary band, and the level of which may be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emissions, parasitic emissions, and intermodulation products, but exclude emissions in the immediate vicinity of the necessary band, which are a result of the modulation process for the transmission of information.

Standard broadcasting station. A broadcasting station operated on a frequency in the band 535-1605 kilocycles.

Standard frequency service. A radiocommunication service for scientific, technical and other purposes, providing the transmission of specified frequencies of stated high precision, intended for general reception.

Stationary satellite. A satellite, the circular orbit of which lies in the plane of the earth's equator and which turns about the polar axis of the earth in the same direction and with the same period as those of the earth's rotation.

Station. One or more transmitters or receivers or a combination of transmitters and receivers, including the accessory equipment, necessary at one location for carrying on a radiocommunication service. Each station shall be classified by the service in which it operates permanently or temporarily.

***Station authorization.** Any construction permit, license, or special temporary authorization issued by the Commission.

Survival craft station. A mobile station in the maritime or aeronautical mobile service intended solely for survival purposes and located on any lifeboat, liferaft or other survival equipment.

Telecommunication. Any transmission, emission or reception of signs, signals, writing, images, and sounds, or intelligence of any nature by wire, radio, optical or other electromagnetic systems.

Telegraphy. A system of telecommunication which is concerned in any process providing transmission and reproduction at a distance of documentary matter, such as written or printed matter or fixed images, or the reproduction at a distance of any kind of information in such form. The foregoing definition appears in the International Telecommunication Convention, but, for the purposes of the Commission's rules, telegraphy shall mean, unless otherwise specified, "A system of telecommunication for the transmission of written matter by the use of a signal code."

Telemetering. The use of telecommunication for automatically indicating or recording measurements at a distance from the measuring instrument.

Telemetering fixed station. A fixed station, the emissions of which are used for telemetering.

Telemetering land station. A land station, the emissions of which are used for telemetering.

Telemetering mobile station. A mobile station, the emissions of which are used for telemetering.

Telephony. A system of telecommunication set up for the transmission of speech or, in some cases, other sounds.

Television. A system of telecommunication for transmission of transient images of fixed or moving objects.

Television broadcasting station. A broadcasting station utilizing both television and telephony to provide combination and simultaneous visual and aural programs intended to be received directly by the general public.

Terrestrial service. Any radio service defined in this Part, other than a space service or the radio astronomy service.

Terrestrial station. A station in a terrestrial service.

Tropospheric scatter. The propagation of radio waves by scattering as a result of irregularities or discontinuities in the physical properties of the troposphere.

Zone station. A fixed station in the public safety (police) radio service using radiotelegraph (A1 emission) for communication with other similar stations in the same zone and with an interzone station.

II Experimental Radio Services (other than broadcast)

Experimental Service. A service in which Hertzian waves are employed for purposes of experimentation in the radio art or for purposes of providing essential communications for research projects which could not be conducted without the benefit of such communications.

Experimental Service (Research). An Experimental Service (1) for research in the radio art not related to the development of an established or proposed new service, or (2) for providing essential communications for research projects which could not be conducted without the benefit of such communications.

Experimental Service (Developmental). An Experimental Radio Service for the development of equipment, engineering or operational data, or techniques for an existing or proposed radio service.

III Radio Frequency Devices

Community antenna television system. A restricted radiation device designed and used for the purpose of distributing television signals by means of conducted or guided radio frequency currents to a multiplicity of receivers outside the confines of a single building. Note: The television signals that are distributed are modulated radio frequency signals and may be: (a) Broadcast signals that have been received and amplified, (b) Broadcast signals that have been received and converted to another frequency, (c) Any other modulated radio frequency signals fed into the system.

Incidental radiation device. A device that radiates radio frequency energy during the course of its operation although the device is not intentionally designed to generate radio frequency energy.

Low power communication device. A low power communication device is a restricted radiation device, exclusive of those employing conducted or guided radio frequency techniques, used for the transmission of signs, signals, (including control signals), writing, images and sounds or intelligence of any nature by radiation of electromagnetic energy. Examples: Wireless microphone, phonograph oscillator, radio controlled garage door opener and radio controlled models.

Restricted radiation device. A device in which the generation of radio frequency energy is intentionally incorporated into the design and in which the radio frequency energy is conducted along wires or is radiated, exclusive of transmitters which require licensing under other parts of this chapter and exclusive of devices in which the radio frequency energy is used to produce physical, chemical, or biological effects in materials and which are regulated under the Rules.

Television broadcast receiver. Apparatus designed to receive television pictures broadcast simultaneously with sound.

IV Industrial, Scientific and Medical Equipment

Industrial heating equipment. Any apparatus which utilizes a radio frequency oscillator or any other type of radio frequency generator and transmits radio frequency energy used for or in connection with industrial heating operations utilized in a manufacturing or production process.

Industrial, scientific and medical equipment (ISM equipment). Devices which use radio waves for industrial, scientific, medical or any other purposes including the transfer of energy by radio and which are neither used nor intended to be used for radiocommunication.

ISM frequency. A frequency assigned for the use of ISM equipment. A specified tolerance is associated with each ISM frequency.

Medical diathermy equipment. Any apparatus (other than surgical diathermy apparatus designed for intermittent operation with low power) which utilizes a radio frequency oscillator or any other type of radio frequency generator and transmits radio frequency energy used for therapeutic purposes.

Miscellaneous equipment. Any apparatus other than that defined in or excepted above in which radio frequency energy is applied to materials to produce physical, biological, or chemical effects such as heating, ionization of gases, mechanical vibrations, hair removal and acceleration of charged particles, which do not involve communications or the use of radio receiving equipment.

Ultrasonic equipment. Any apparatus which generates radio frequency energy and utilizes that energy to excite or drive an electromechanical transducer for the production of sonic or ultrasonic mechanical energy for industrial, scientific, medical or other noncommunication purposes.

V Broadcast Services

A. STANDARD BROADCAST STATIONS

1. General Definitions

Auxiliary transmitter. A transmitter maintained only for transmitting the regular programs of a station in case of failure of the main transmitter.

*Broadcast day. Period of time between local sunrise and 12 midnight local standard time.

*Daytime. Period of time between local sunrise and local sunset.

Dominant station. A Class I station operating on a clear channel.

*Experimental period. That time between 12 midnight and local sunrise. This period may be used for experimental purposes in testing and maintaining apparatus by the licensee of any standard broadcast station on its assigned frequency and with its authorized power, provided no interference is caused to other stations maintaining a regular operating schedule within such period. No station licensed for "daytime" or "specified hours" of operation may broadcast any regular or scheduled program during this period.

*Nighttime. Time between local sunset and 12 midnight local standard time.

Portable transmitter. A transmitter so constructed that it may be moved about conveniently from place to place, and is in fact so moved about from time to time, but not ordinarily used while in motion. In the standard broadcast band, such a transmitter is used in making field intensity measurements for locating a transmitter site for a standard broadcast station. A portable broadcast station will not be licensed in the standard broadcast band for regular transmission of programs intended to be received by the public.

Secondary station. Any station except a Class I station operating on a clear channel.

Service areas. (a) Primary service area of a broadcast station means the area in which the groundwave is not subject to objectionable interference or objectionable fading. (b) Secondary service area of a broadcast station means the area served by the skywave and not subject to objectionable interference. The signal is subject to intermittent variations in intensity. (c) Intermittent service area of a broadcast station means the area receiving service from the groundwave but beyond the primary service area and subject to some interference and fading.

***Standard broadcast band.** The band of frequencies extending from 535 to 1605 kilocycles.

***Standard broadcast channel.** The band of frequencies occupied by the carrier and two sidebands of a broadcast signal with the carrier frequency at the center. Channels shall be designated by their assigned carrier frequencies. The 107 carrier frequencies assigned to standard broadcast stations shall begin at 540 kilocycles and be in successive steps of 10 kilocycles.

***Standard broadcast station.** A broadcasting station licensed for the transmission of radiotelephone emissions primarily intended to be received by the general public and operated on a channel in the band 535-1605 kilocycles.

***Sunrise and sunset.** For each particular location and during any particular month, the time of sunrise and sunset as specified in the instrument of authorization.

2. Technical Definitions

***Antenna current.** The radio frequency current in the antenna with no modulation.

***Antenna power.** Antenna input power or antenna power means the product of the square of the antenna current and the antenna resistance at the point where the current is measured.

***Antenna resistance.** Total resistance of the transmitting antenna system at the operating frequency and at the point at which the antenna current is measured.

Blanketing. Form of interference which is caused by the presence of a broadcast signal of 1 v/m or greater intensity in the area adjacent to the antenna of the transmitting station. The 1 v/m contour is referred to as the blanket contour and the area within this contour is referred to as the blanket area.

Combined audio harmonics. Arithmetical sum of the amplitudes of all the separate harmonic components. Root sum square harmonic readings may be accepted under conditions prescribed by the Commission.

Effective field. Effective field or effective field intensity is the root-mean-square (RMS) value of the inverse distance fields at a distance of 1 mile from the antenna in all directions in the horizontal plane.

***Grid modulation.** Modulation produced by introduction of the modulating wave into any of the grid circuits of any tube in which the carrier frequency wave is present.

***High level modulation.** Modulation produced in the plate circuit of the last radio stage of the system.

***Last radio stage.** Oscillator or radio-frequency-power amplifier stage which supplies power to the antenna.

***Low level modulation.** Modulation produced in an earlier stage than the final.

Maximum percentage of modulation. Greatest percentage of modulation that may be obtained by a transmitter without producing in its output harmonics of the modulating frequency in excess of those permitted by these regulations.

Maximum rated carrier power. Maximum power at which the transmitter can be operated satisfactorily. It is determined by the design of the transmitter and the type and number of vacuum tubes used in the last radio stage.

***Modulated stage.** The radio frequency stage to which the modulator is coupled and in which the continuous wave (carrier wave) is modulated in accordance with the system of modulation and the characteristics of the modulating wave.

***Modulator stage.** The last amplifier stage of the modulating wave which modulates a radio frequency stage.

***Operating power.** Power that is actually supplied to the radio station antenna.

***Percentage modulation (amplitude).** The ratio of half the difference between the maximum and minimum amplitudes of the amplitude modulated wave to the average amplitude expressed in percentage.

***Plate modulation.** Modulation produced by introduction of the modulating wave into the plate circuit of any tube in which the carrier frequency wave is present.

***Plate input power.** The product of the direct plate voltage applied to the tubes in the last radio stage and the total direct current flowing to the plates of these tubes, measured without modulation.

B. FM STATIONS

1. Frequency Modulation

Antenna height above average terrain. The average of the antenna heights above the terrain from 2 to 10 miles from the antenna for the eight directions spaced evenly for each 45 degrees of azimuth starting with True North. (In general, a different antenna height will be determined in each direction from the antenna. The average of these various heights is considered the antenna height above the average terrain. In some cases less than eight directions may be used.) Where circular or elliptical polarization is employed, the antenna height above average terrain shall be based upon the height of the radiation center of the antenna which transmits the horizontal component of radiation.

***Antenna power gain.** The square of the ratio of the root-mean-square free space field strength produced at 1 mile in the horizontal plane, in millivolts per meter for 1 kilowatt antenna input power to 137.6 mv/m. This ratio should be expressed in decibels (db). (If specified for a particular direction, antenna power gain is based on the field strength in that direction only.)

***Center frequency.** (1) The average frequency of the emitted wave when modulated by a sinusoidal signal. (2) The frequency of the emitted wave without modulation.

***Effective radiated power.** The product of the antenna power (transmitter output power less transmission line loss) times (1) the antenna power gain, or (2) the antenna field gain squared. Where circular or elliptical polarization is employed, the term effective radiated power is applied separately to the horizontal and vertical components of radiation. For allocation purposes, the effective radiated power authorized is the horizontally polarized component of radiation only.

***FM broadcast band.** The band of frequencies extending from 88 to 108 megacycles per second, which includes those assigned to noncommercial educational broadcasting.

***FM broadcast channel.** A band of frequencies 200 kc/s wide and designated by its center frequency. Channels for FM broadcast stations begin at 88.1 mc/s and continue in successive steps of 200 kc/s to and including 107.9 mc/s.

***FM broadcast station.** A station employing frequency modulation in the FM broadcast band and licensed primarily for the transmission of radiotelephone emissions intended to be received by the general public.

***Field strength.** The electric field strength in the horizontal plane.

Free space field strength. The field strength that would exist at a point in the absence of waves reflected from the earth or other reflecting objects.

***Frequency Modulation.** A system of modulation where the instantaneous radio frequency varies in proportion to the instantaneous amplitude of the modulating signal (amplitude of modulating signal to be measured after pre-emphasis, if used) and the instantaneous radio frequency is independent of the frequency of the modulating signal.

***Frequency swing.** The instantaneous departure of the frequency of the emitted wave from the center frequency resulting from modulation.

***Multiplex transmission.** The simultaneous transmission of two or more signals within a single channel. Multiplex transmission as applied to FM broadcast stations means the transmission of facsimile or other signals in addition to the regular broadcast signals.

***Percentage modulation.** The ratio of the actual frequency swing to the frequency swing defined as 100 percent modulation, expressed in percentage. For FM broadcast stations, a frequency swing of ± 75 kilocycles is defined as 100 percent modulation.

2. Stereophonic Broadcasting

***Cross-talk.** An undesired signal occurring in one channel caused by an electrical signal in another channel.

FM stereophonic broadcast. The transmission of a stereophonic program by a single FM broadcast station utilizing the main channel and a stereophonic subchannel.

***Left (or right) signal.** The electrical output of a microphone or combination of microphones placed so as to convey the intensity, time, and location of sounds originating predominantly to the listener's left (or right) of the center of the performing area.

***Left (or right) stereophonic channel.** The left (or right) signal as electrically reproduced in reception of FM stereophonic broadcasts.

***Main channel.** The band of frequencies from 50 to 15,000 cycles per second which frequency-modulate the main carrier.

***Pilot subcarrier.** A subcarrier serving as a control signal for use in the reception of FM stereophonic broadcasts.

***Stereophonic separation.** The ratio of the electrical signal caused in the right (or left) stereophonic channel to the electrical signal caused in the left (or right) stereophonic channel by the transmission of only a right (or left) signal.

***Stereophonic subcarrier.** A subcarrier having a frequency which is the second harmonic of the pilot subcarrier frequency and which is employed in FM stereophonic broadcasting.

***Stereophonic subchannel.** The band of frequencies from 23 to 53 kilocycles per second containing the stereophonic subcarrier and its associated sidebands.

3. Facsimile

Available line. The portion of the total length of scanning line that can be used specifically for picture signals.

Index of cooperation. The product of the number of lines per inch, the available line length in inches, and the reciprocal of the line-use ratio (e.g., 105 × 8.2 × 8/7 = 984).

Line-use ratio. The ratio of the available line to the total length of scanning line.

Optical density. The logarithm (to the base 10) of the ratio of incident to transmitted or reflected light.

Rectilinear scanning. The process of scanning an area in a predetermined sequence of narrow straight parallel strips.

C. TELEVISION BROADCAST STATIONS

Amplitude Modulation (AM). A system of modulation in which the envelope of the transmitted wave contains a component similar to the waveform of the signal to be transmitted.

Antenna height above average terrain. The average of the antenna heights above the terrain from two to ten miles from the antenna for the eight directions spaced evenly for each 45 degrees of azimuth starting with True North. (In general, a different antenna height will be determined in each direction from the antenna. The average of these various heights is considered the antenna height above the average terrain. In some cases less than 8 directions may be used.

Antenna power gain. The square of the ratio of the root-mean-square free space field intensity produced at one mile in the horizontal plane, in millivolts per meter for one kilowatt antenna input power to 137.6 mv/m. This ratio should be expressed in decibels (db). (If specified for a particular direction, antenna power gain is based on the field strength in that direction only.)

***Aspect ratio.** The ratio of picture width to picture height as transmitted. The standard now used is 4 to 3.

***Aural transmitter.** The radio equipment for the transmission of the aural signal only.

***Aural center frequency.** (1) The average frequency of the emitted wave when modulated by a sinusoidal signal; (2) the frequency of the emitted wave without modulation.

***Blanking level.** The level of the signal during the blanking interval, except the interval during the scanning synchronizing pulse and the chrominance subcarrier synchronizing burst.

***Chrominance.** The colorimetric difference between any color and a reference color of equal luminance, the reference color having a specific chromaticity.

***Chrominance subcarrier.** The carrier which is modulated by the chrominance information.

***Color transmission.** The transmission of color television signals which can be reproduced with different values of hue, saturation, and luminance.

***Effective radiated power.** The product of the antenna input power and the antenna power gain. This product should be expressed in kilowatts and in decibels above one kilowatt (dbk). (If specified for a particular direction, effective radiated power is based on the antenna power gain in that direction only. The licensed effective radiated power is based on the average antenna power gain for each horizontal plane direction.)

***Field.** Scanning through the picture area once in the chosen scanning pattern. In the line interlaced scanning pattern of two to one, the scanning of the alternate lines of the picture area once.

***Frame.** Scanning all of the picture area once. In the line interlaced scanning pattern of two to one, a frame consists of two fields.

***Free space field intensity.** The field intensity that would exist at a point in the absence of waves reflected from the earth or other reflecting objects.

***Frequency swing.** The instantaneous departure of the frequency of the emitted wave from the center frequency resulting from modulation.

***Interlaced scanning.** A scanning process in which successively scanned lines are spaced an integral number of line widths, and in which the adjacent lines are scanned during successive cycles of the field frequency.

***Luminance.** Luminous flux emitted, reflected, or transmitted per unit solid angle per unit projected area of the source.

***Monochrome transmission.** The transmission of television signals which can be reproduced in gradations of a single color only.

***Negative transmission.** Where a decrease in initial light intensity causes an increase in the transmitted power.

Noise figure of a television broadcast receiver. The ratio of (1) the total noise power delivered by the receiver into its output termination when the noise temperature of its input termination is standard (290°K) at all frequencies, to (2) the portion thereof engendered by the input termination. Note: For a television broadcast receiver, portion (2) includes only that noise from the input termination which appears in the output via the principal frequency transformation and does not include spurious contributions such as those from image frequency transformation.

Peak picture sensitivity for television broadcast receiver. The lowest input signal which results in standard picture test output when the receiver is tuned for maximum picture output. Note: Standard picture test output for symmetrical sine wave modulation shall be 20 volts peak-to-peak between the control elements of the picture tube.

***Peak power.** The power over a radio frequency cycle corresponding in amplitude to synchronizing peaks.

Percentage modulation. As applied to frequency modulation, the ratio of the actual frequency swing to the frequency swing defined as 100 percent modulation, expressed in percentage. For the aural transmitter of television broadcast stations, a frequency swing of ± 25 kilocycles is defined as 100 percent modulation.

Polarization. The direction of the electric field as radiated from the transmitting antenna.

***Reference black level.** The level corresponding to the specified maximum excursion of the luminance signal in the black direction.

***Reference white level of the luminance signal.** The level corresponding to the specified maximum excursion of the luminance signal in the white direction.

***Scanning.** The process of analyzing successively, according to a predetermined method, the light values of picture elements constituting the total picture area.

***Scanning line.** A single continuous narrow strip of the picture area containing highlights, shadows, and halftones, determined by the process of scanning.

***Standard television signal.** A signal which conforms to the television transmission standards.

***Synchronization.** The maintenance of one operation in step with another.

***Television broadcast band.** The frequencies in the band extending from 54 to 890 megacycles which are assignable to television broadcast stations. These frequencies are 54 to 72 megacycles (channels 2 through 4), 76 to 88 megacycles (channels 5 and 6), 174 to 216 megacycles (channels 7 through 13), and 470 to 890 megacycles (channels 14 through 83).

Television broadcast station. A station in the television broadcast band transmitting simultaneous visual and aural signals intended to be received by the general public.

Television broadcast booster station. A station in the broadcasting service operated for the sole purpose of retransmitting the signals of a television broadcast station by amplifying and reradiating such signals which have been received directly through space, without significantly altering any characteristic of the incoming signal other than its amplitude.

Television broadcast translator station. A station in the broadcasting service operated for the purpose of retransmitting the signals of a television broadcast station, another television broadcast translator station, or a television translator relay station, by means of direct frequency conversion and amplification of the incoming signals without significantly altering any characteristic of the incoming signal other than its frequency and amplitude, for the purpose of providing television reception to the general public.

***Television channel.** A band of frequencies 6 megacycles wide in the television broadcast band and designated either by number or by the extreme lower and upper frequencies.

Television intercity relay station. A fixed station used for intercity transmission of television program material and related communications for use by television broadcast stations.

Television pickup station. A land mobile station used for the transmission of television program material and related communications from the scenes of events occurring at points removed from television broadcast station studios to television broadcast stations.

Television STL station (studio-transmitter link). A fixed station used for the transmission of television program material and related communications from the studio to the transmitter of a television broadcast station.

***Television transmission standards.** The standards which determine the characteristics of a television signal as radiated by a television broadcast station.

Television transmitter. The radio transmitter or transmitters for the transmission of both visual and aural signals.

Television translator relay station. A fixed station used for relaying the signals of television broadcast stations to television broadcast translator stations.

UHF translator. A television broadcast translator station operating on a UHF television broadcast channel.

UHF translator signal booster. A station in the broadcasting service operated for the sole purpose of retransmitting the signals of a UHF translator station by amplifying and reradiating such signals which have been received directly through space, without significantly altering any characteristic of the incoming signal other than its amplitude.

VHF translator. A television broadcast translator station operating on a VHF television broadcast channel.

***Vestigial sideband transmission.** A system of transmission wherein one of the generated sidebands is partially attenuated at the transmitter and radiated only in part.

Visual carrier frequency. The frequency of the carrier which is modulated by the picture information.

Visual transmitter. The radio equipment for the transmission of the visual signal only.

***Visual transmitter power.** The peak power output when transmitting a standard television signal.

D. INTERNATIONAL BROADCAST STATIONS

Autumnal equinox season. That period of any calendar year starting at 0000 EST on 1 August and ending at 2400 EST on 31 October.

Contract operation. Any nongovernment operation of an international broadcast station pursuant to a contract with an agency of the United States Government and subject to Governmental control as to program content, target areas to be covered, and time of broadcast.

Day. Any twenty-four hour period beginning 0000 EST and ending 2400 EST.

Delivered median field intensity or field intensity. The field intensity incident upon the target area expressed in microvolts per meter, or decibels above one microvolt per meter, which is exceeded by the hourly median value on 50 percent of the days of the reference month.

Frequency-hour. One frequency used for one hour.

International broadcast station. A broadcasting station employing frequencies allocated to the broadcasting service between 5950 and 26100 kc, whose transmissions are intended to be received directly by the general public in foreign countries.

Maximum usable frequency (MUF). The highest frequency which is returned to the surface of the earth for a particular path and time of day on 50 percent of the days of the reference month.

Optimum working frequency (OWF). The frequency which is returned to the surface of the earth for a particular path and time of day on 90 percent of the days of the reference month.

Primary station. The television broadcast station radiating the signals which are retransmitted by a television broadcast booster station or translator station.

Private operation. Any nongovernment operation of an International Broadcast station which is not contract operation.

Reference month. The middle month of any season in "Daily Frequency Hour Availability Table."

Summer season. That period of any calendar year starting at 0000 EST on 1 May and ending at 2400 EST on 31 July.

Sunspot number. The predicted 12 month running average of the number of sunspots for any month as indicated in the National Bureau of Standards CRPL Series D publications.

Target area. Geographic area in which the reception of particular programs is specifically intended and in which adequate broadcast coverage is contemplated.

Vernal equinox season. That period of any calendar year starting at 0000 EST on 1 February and ending at 2400 EST on 30 April.

Winter season. That period of any calendar year starting at 0000 EST on 1 November and ending at 2400 EST on 31 January.

E. EMERGENCY ACTION NOTIFICATION SYSTEM AND THE EMERGENCY BROADCAST SYSTEM

Emergency Action Notification System. The System by which all licensees and regulated services of the Federal Communications Commission, and the general public, are notified (with or without an Attack Warning) of the existence of an Emergency Action Condition resulting from a grave national crisis or war. The Emergency Action Notification System and the Emergency Broadcast System Implementation System consist only of the following approved facilities, systems, and arrangements:

(a) First Method. From the President of the United States via the White House Communications Agency to the Associated Press (AP) and United Press International (UPI); thence via automatic selective switching and teletype Emergency Action Notification to all standard, FM, and television broadcast and other stations subscribing to the AP and UPI Radio Wire Teletype Networks.

(b) Second Method. From the President of the United States via the White House Communications Agency to specified control points of the nationwide commercial Radio and Television Broadcast Networks, the American Telephone and Telegraph Co. and other specified points via a dedicated teletypewriter network; thence to all affiliates via any available internal commercial radio and television network alerting facilities.

(c) Third Method. Off-the-air monitoring of specified standard, FM, and television broadcast stations by standard, FM, and television broadcast stations and other licensees and regulated services for receipt of the Emergency Action Notification. All broadcast licensees are required to install, maintain, and operate radio receiving equipment for receipt of the Emergency Action Notification.

(d) Fourth Method. Off-the-air monitoring of standard, FM, and television broadcast stations by the general public who are listening or viewing or whose radio or television receivers are equipped for actuation by the Attention Signal to receive the Emergency Action Notification.

Attention Signal. The signaling arrangement transmitted by all standard, FM, and television broadcast stations for the purpose of actuating muted standard, FM, and television receivers.

***Emergency Action Notification.** Notice (with or without an Attack Warning) to all licensees and regulated services of the Federal Communications Commission and to the general public of the existence of an Emergency Action Condition. The Emergency Action Notification is released upon direction of the President of the United States and is disseminated only via the Emergency Action Notification System.

***Emergency Action Condition.** The Emergency Action Condition is the period of time between the transmission of an Emergency Action Notification and the transmission of the Emergency Action Condition Termination.

***Emergency Action Condition Termination.** The Emergency Action Condition Termination is the notice to all licensees and regulated services of the Federal Communications Commission and to the general public of the termination of an Emergency Action Condition. The Emergency Action Condition Termination is released upon direction of the President of the United States and is disseminated only via the Emergency Action Notification System.

Emergency Broadcast System (EBS). System of facilities and personnel of nongovernment broadcast stations and other authorized facilities licensed or regulated by the Federal Communications Commission, including approved and authorized integral facilities or systems, arrangements, procedures, and interconnecting facilities, which have been authorized by the Commission to operate in a controlled manner during a grave national crisis or war.

***Basic Emergency Broadcast System (EBS) Plan.** Plan containing, among other things, approved basic concepts and designated national-level systems, arrangements, procedures, and interconnecting facilities to satisfy the White House Statement of Requirements for Presidential Messages and National Programing and News. Provision is made therein for the development, designation, and approval of facilities, mutually compatible operational arrangements, procedures, and interconnecting facilities to satisfy the Department of Defense (Office of Civil Defense) statement of requirements for the dissemination of emergency information and instructions by Regional, State, and Operational Area (Local) authorities in addition to Presidential Messages and National Programing and News, as set forth above.

NIAC Order. Service order previously filed with the American Telephone and

Telegraph Co. providing for approved arrangements for program origination reconfiguration of the major commercial Radio and Television (aural) Broadcast Networks (except UPI Audio) voluntarily participating in the Emergency Broadcast System (EBS). Broadcast networks presently participating are American Broadcasting Co. (ABC), Columbia Broadcasting System (CBS), Mutual Broadcasting System (MBS), National Broadcasting Co. (NBC), Intermountain Network (IMN), and the United Press International Audio (UPI). Any NIAC Order must meet White House requirements and may be activated only when requested by the White House Communications Agency in accordance with approved established procedures.

National Defense Emergency Authorization (NDEA). Authorization issued by the Federal Communications Commission only to the licensees of broadcast stations to permit controlled operation of such stations, as well as associated auxiliary broadcast stations on a voluntary organized basis during an Emergency Action Condition, also consistent with the Basic Emergency Broadcast System (EBS) Plan, including the annexes and supplements to that plan. A broadcast station licensee will be issued a National Defense Emergency Authorization only in accordance with the Criteria for Eligibility set forth in the Basic Emergency Broadcast System (EBS) Plan, which will remain valid concurrently with the term of the broadcast station license, so long as the station licensee continues to comply with the Criteria for Eligibility.

Primary Station National Defense Emergency Authorization (NDEA). Authorization issued to one or more broadcast station licensees in an Operational Area assigning such licensees the responsibility for broadcasting a common emergency program for the initial period of, or for the duration of, and Emergency Action Condition. Broadcasts by such stations are intended for direct public reception in an Operational Area, as specified in an approved Detailed State Emergency Broadcast System (EBS) Operational Plan.

Alternate Station National Defense Emergency Authorization (NDEA). Authorization issued to one or more broadcast licensees in an Operational Area assigning such licensees as specified alternates. An Alternate station will assume broadcasting responsibility in accordance with the Detailed State Emergency Broadcast System (EBS) Operational Plan.

Primary Relay National Defense Emergency Authorization (NDEA). Authorization issued to one or more broadcast licensees in an Operational Area assigning such licensees the function of emergency program distribution or relay service of emergency programing to stations holding Primary or Alternate Station National Defense Emergency Authorizations, in accordance with an approved Detailed State Emergency Broadcast System (EBS) Operational Plan. A Relay station will not generally broadcast emergency program material intended for direct public reception.

Alternate Relay National Defense Emergency Authorization (NDEA). Authorization issued to one or more broadcast licensees in an Operational Area assigning such licensees as specified alternates to stations holding Primary Relay National Defense Emergency Authorizations. In the event a Primary Relay station is unable to assume its initial operational functions, or discontinues such operation for any reason, an alternate Relay station will assume those operational functions, in accordance with the "alternate" designations (1st, 2d, 3d, 4th, etc.) contained in an approved Detailed State Emergency Broadcast System (EBS) Operational Plan.

Non-NDEA Station. A broadcast station which is not voluntarily participating in the Emergency Broadcast System (EBS) and does not hold a National Defense Emergency Authorization. Such stations are required to discontinue operations for the duration of an Emergency Action Condition.

Detailed Regional Emergency Broadcast System (EBS) Operational Plan. Plan providing for a regional emergency programing origination capability at the Federal Regional Center in coordination with the State Industry Advisory Committees and integrated into the Detailed State Emergency Broadcast System (EBS) Operational Plans within the Federal Region as a coordinated Regional/State operation.

Detailed State Emergency Broadcast System (EBS) Operational Plan. Plan containing the designation of facilities, approved detailed mutually compatible operational arrangements, procedures, instructions, and interconnecting facilities to satisfy the requirements of the President and the Federal Government, as well as State and Operational Area (Local) authorities for communicating with the general public during the Emergency Action Condition. Such a plan includes approved and authorized detailed emergency operational communications facilities, systems, procedures, and interconnecting systems.

Operational Area. Geographical area which may encompass a number of contiguous communities, as mutually determined by the State Industry Advisory Committee and State authorities, and as delineated in the approved Detailed State Emergency Broadcast System, (EBS) Operational Plan.

Common Program Control Broadcast Station. A Primary NDEA broadcast station in each Operational Area assigned the responsibility for coordinating the operations for the broadcasting of the common program for the Operational Area.

F. REMOTE PICKUP BROADCAST STATIONS

Associated broadcasting station. The broadcasting station with which a remote pickup broadcast base or mobile station is licensed as an auxiliary and with which it is principally used.

Attended operation. Operation of a station by a qualified operator on duty at the place where the transmitting apparatus is located with the transmitter in plain view of the operator.

Automatic mobile relay station. A remote pickup broadcast base station actuated by automatic means and used to relay communications between base and mobile stations, between mobile stations, and from mobile stations licensed under the rules of this subpart, to broadcast stations.

Operational communications. Communications related to the technical operation of a broadcasting station and its auxiliaries, other than the transmission of program material and cues and orders directly concerned therewith.

Remote control operation. Operation of a station by a qualified operator at a control position from which the transmitter is not visible but which control position is equipped with suitable control and telemetering circuits so that the essential functions which could be performed at the transmitter can also be performed from the control point.

Remote pickup broadcast base station. A base station licensed for communicating with remote pickup broadcast mobile stations.

Remote pickup broadcast mobile station. A land mobile station licensed for the transmission of program material and related communications from the scene of events, which occur outside a studio, to broadcasting stations and for communicating with other remote pickup broadcast base and mobile stations. (As used in this part, land mobile station includes hand-carried, pack-carried, and other portable transmitters.)

Studio. Any room or series of rooms equipped for the regular production of broadcast programs of various kinds. A broadcasting booth at a stadium, convention hall, church, or other similar place is not considered to be a studio.

VI Maritime Services (Land and Shipboard Stations)

A. GENERAL

Categories of ships. (1) Where use of the term "passenger ship" or "cargo ship" occurs in reference to the provisions of Part II of Title III of the Communications Act, such use of the term shall be construed as follows: A ship is a passenger ship if it carries or is licensed or certificated to carry more than twelve passengers. A cargo ship is any ship not a passenger ship. (2) Where use of the term "passenger ship" or "cargo ship" occurs in reference to the radio provisions of the Safety Convention or in reference to frequency assignment, such use of the term shall be construed as follows: A ship is a passenger ship if it carries more than twelve passengers. A cargo ship is any ship not a passenger ship. (3) A "commercial transport vessel" is any ship or vessel which is used primarily in commerce (i) for transporting persons or goods to or from any harbor(s) or port(s) or between places within a harbor or port area, or (ii) in connection with the construction, change in construction, servicing, maintenance, repair, loading, unloading, movement, piloting, or salvaging of any other ship or vessel. (4) The term "passenger carrying vessel," as used in this part solely in reference to requirements of the Great Lakes Agreement, means any vessel transporting persons for hire.

Day. (1) Where the word "day" is applied to the use of a specific frequency assignment or to a specific authorized transmitter-power, such use of the word "day" shall be construed to mean transmission on such frequency assignment or with such authorized transmitter-power during that period of time included between one hour after local sunrise and one hour before local sunset. (2) Where the word "day" occurs in reference to watch requirements, or to the provisions of §83.449, such use of the word "day" shall be construed to mean the calendar day, from midnight to midnight, local ship's time.

Destination. In reference to the Great Lakes Agreement this term means a port which a vessel enters for the purpose of initiating or completing the specific activity which characterizes the vessel. For example, with respect to vessels carrying passengers or goods, a port at which a vessel, either partially or completely, loads or unloads passengers or goods, would constitute its destination.

Great Lakes. This term, as used in this part solely in reference to the Great Lakes Agreement, means all of the Great Lakes, their connecting and tributary waters, and the St. Lawrence River as far east as the lower exit of the Lachine Canal and the Victoria Bridge at Montreal, but shall not include tributary rivers which are not also connecting rivers, and shall not include the Niagara River (including the Black Rock Canal).

Installed. As used in this part with respect to the requirements of radio apparatus authorized under the provisions of this part for use on board ship or in stations subject to this part, the term "installed" means installed on board the particular ship or in the particular station to which the pertinent rule or regulation, involving the use of this term, is applied.

Mile. As used in this part, the term "mile" means a statute mile or 5,280 feet.

Safety Convention Certificates. (1) Nuclear Passenger Ship Safety Certificate. A certificate issued after inspection and survey to a nuclear passenger ship which complies with the relevant requirements of the Safety Convention. **(2) Passenger Ship Safety Certificate.** A certificate issued after inspection and survey to a passenger ship which complies with the relevant requirements of the Safety Convention. **(3) Nuclear Cargo Ship Safety Certificate.** A certificate issued after inspection and survey to a nuclear cargo ship which complies with the relevant requirements of the Safety Convention. **(4) Cargo Ship Safety Radiotelegraphy Certificate.** A certificate issued after inspection to a cargo ship which complies with the Safety Convention radio requirements applicable to cargo ships carrying a radiotelegraph station for the purpose of meeting such requirements. **(5) Cargo Ship Safety Radiotelephony Certificate.** A certificate issued after inspection to a cargo ship which complies with the Safety Convention radio requirements applicable to cargo ships carrying a radiotelephone station for the purpose of meeting such requirements. **(6) Exemption Certificate.** A certificate issued to a ship which is granted partial, conditional, or complete exemption from applicable provisions of the Safety Convention.

Ship or vessel. "Ship" or "vessel" includes every description of watercraft or other artificial contrivance, except aircraft, used or capable of being used as a means of transportation on water whether or not it is actually afloat.

B. MARITIME MOBILE SERVICE

Base Station. A land station in the land mobile service carrying on a service with land mobile stations.

Class I coast station. A coast station (public or limited) licensed to provide a maritime mobile service to ships at sea, including such service over distances up to several thousand miles, whose frequency assignment for this purpose includes appropriate frequencies below 150 kc/s or between 5,000 kc/s and 25,500 kc/s.

Class II coast station. A coast station (public or limited) licensed to provide a maritime mobile service, primarily of a regional character, whose frequency assignment does not include any frequency below 150 kc/s or between 5,000 kc/s and 25,000 kc/s except on a secondary basis under specified conditions intended to minimize the possibility of interference to other stations having priority on these frequencies.

Class III coast station. A coast station (public or limited) licensed to provide a maritime mobile service, primarily of a local character, whose frequency assignment does not include any frequency below 25,000 kc/s.

Coast station. A land station in the maritime mobile service.

Land mobile station. A mobile station in the land mobile service capable of surface movement within the geographical limits of a country or continent.

Land station. A station in the mobile service not intended to be used while in motion.

Limited coast station. A coast station, not open to public correspondence, which serves the operational and business needs of ships.

Limited ship station. A ship station not open to public correspondence.

Marine-utility coast station. A coast station, readily portable for use as a limited coast station at unspecified points ashore within a designated local area.

Marine-utility ship station. A ship station, readily portable for use as a limited ship station on mobile vessels within a designated local area.

Marine-utility station. A coast or ship station in the maritime mobile service having a frequency assignment which is available for both marine-utility coast stations and marine-utility ship stations and licensed under one station authorization to operate as either a marine-utility coast station or a marine-utility ship station according to its location.

Maritime and land mobile service. (1) **Maritime mobile service.** A mobile service between coast stations and ship stations, or between ship stations, in which survival craft stations may also participate. (Aircraft stations, when transmitting on frequencies allocated to the maritime mobile service, may communicate in this service with ship stations and coast stations.) (2) **Land mobile service.** A mobile service between base stations and land mobile stations, or between land mobile stations. (Only land mobile service carried on exclusively for maritime purposes is governed by this part.)

Mobile service. A service of radiocommunication between mobile and land stations, or between mobile stations.

Mobile station. A station in the mobile service intended to be used while in motion or during halts at unspecified points.

Operational designator. The letter "A," "B," or "F," appended to the term "class I," "class II," or "class III," designates that the coast station is licensed to render its normal service by means of (A) telegraphy, (B) telephony, or (F) facsimile. The designator "L" means "local" and is used to indicate (in lieu of a separate class III coast station license for the same station) that a class I or a class II station provides maritime mobile service of a local character on a frequency or frequencies above 30 mc/s in addition to its service on other frequencies.

Public coast station. A coast station open to public correspondence.

Public ship station. (1) A ship station open to public correspondence. (2) Public ship stations authorized to employ telegraphy for public correspondence are further classified according to their hours of service for telegraphy as designated in this section: (a) **First Category.** These stations carry on a continuous service of public correspondence. (b) **Second Category.** These stations carry on a designated service of public correspondence of prescribed but limited duration at least during the period designated for ship stations of the second category by the International Radio Regulations or, in the case of voyages of short duration, as otherwise designated by the Commission in accordance with those Regulations. (c) **Third Category.** These stations carry on a service of public correspondence, the duration of which is prescribed but is less than that of stations of the "Second Category," or is not prescribed but is determined by the master of vessel pursuant to his authority under Section 360 of the Communications Act.

Shipyard land mobile unit. A land vehicle operated and controlled by a shipyard and used for the transportation of shipyard personnel, material, or supplies.

Shipyard base station. A land station, licensed and operated primarily as a limited coast station in the maritime mobile service, which is authorized additionally to be operated on a secondary basis as a base station for communication with shipyard mobile stations of the same licensee within a local geographic area designated by the Commission.

Ship station. A mobile station in the maritime mobile service located on board a vessel, other than a survival craft, which is not permanently moored.

Shipyard mobile station. A land mobile station on a shipyard land mobile unit used for communication solely with one or more shipyard base stations of the same licensee within a local geographic area designated by the Commission.

Survival craft station. A mobile station in the maritime or aeronautical mobile service intended solely for survival purposes and located on any lifeboat, liferaft or other survival equipment.

C. MARITIME RADIO DETERMINATION SERVICE

Direction finder (radio compass). Apparatus capable of receiving clearly perceptible radio signals and capable of taking bearings on these signals from which the true bearing and direction of the point of origin of such signals with respect to the point of reception may be determined.

Maritime radiodetermination service. A radiodetermination service intended for the benefit of ships.

Maritime radiolocation service. A radiolocation service intended for the benefit of ships.

Maritime radionavigation service. A radionavigation service intended for the benefit of ships.

Radar. A radiodetermination system based on the comparison of reference signals with radio signals reflected, or retransmitted, from the position to be determined.

Radiodetermination. The determination of position, or the obtaining of information relating to position, by means of the propagation properties of radio waves.

Radiodetermination service. A service involving the use of radiodetermination.

Radio direction finding. Radiodetermination using the reception of radio waves for the purpose of determining the direction of a station or object.

Radiolocation. Radiodetermination used for purposes other than those of radionavigation.

Radiolocation land station. A station in the radiolocation service not intended to be used while in motion.

Radiolocation mobile station. A station in the radiolocation service intended to be used while in motion or during halts at unspecified points.

Radiolocation service. A radiodetermination service involving the use of radiolocation.

Radionavigation. Radiodetermination used for the purposes of navigation, including obstruction warning.

Radionavigation land station. A station in the radionavigation service not intended to be used while in motion.

Radionavigation mobile station. A station in the radionavigation service intended to be used while in motion or during halts at unspecified points.

Radionavigation service. A radiodetermination service involving the use of radionavigation.

Ship radar station. A ship radionavigation station utilizing radar.

Ship radiolocation station. A radiolocation mobile station located on board a ship and used solely for maritime radiolocation service.

Ship radiolocation test station. A ship radiolocation station used solely for testing maritime radionavigation apparatus incident to its manufacture, installation, repair, servicing, and/or maintenance.

Ship radionavigation station. A radionavigation mobile station located on board a ship and used solely for maritime radionavigation service.

Shore radar station. A shore radionavigation station utilizing radar.

Shore radiolocation station. A radiolocation land station performing a maritime radiolocation service.

Shore radiolocation test station. A shore radiolocation station used solely for testing maritime radiodetermination apparatus incident to its manufacture, installation, repair, servicing, or maintenance.

Shore radiolocation training station. A shore radiolocation station used solely to train and qualify persons in the effective use of maritime radiodetermination.

Shore radionavigation station. A radionavigation land station performing a maritime radionavigation service.

D. MARITIME FIXED SERVICES

Marine control station. An operational fixed station used to control the emissions or operation of a coast station at a separate location.

Marine fixed station. A fixed station, used primarily for safety communication which is established at a designated location in a water area of, or contiguous to, the United States, and isolated from the mainland by water or marsh.

Marine receiver-test station. A fixed station used to simulate transmission from a ship station to a coast station for the purpose of periodically testing the normal receiving installation of a licensed coast station to determine that such receiving installation is in good working condition.

Marine repeater station. An operational fixed station used to retransmit, to a point of destination or to a message routing center, radiocommunications received at a coast station from ship or aircraft stations in the maritime mobile service.

Marine relay station. An operational fixed station used for communication between coast stations or between a coast station and an associated remote control point, which is intended to expedite the movement of message traffic to or from mobile stations in the maritime mobile service.

Operational fixed station. A fixed station, not open to public correspondence, operated by and for the sole use of those agencies operating their own radiocommunication facilities in the public safety, industrial, land transportation, marine, or aviation services.

E. DEVELOPMENTAL MARITIME STATIONS

Developmental fixed station. A fixed station operated for the express purpose of developing equipment or a technique solely for use only in that portion of the nongovernment fixed service which has been specifically allocated the authorized frequency (or frequencies) of the developmental fixed station.

Developmental land station. A land station operated for the express purpose of developing equipment or a technique solely for use only in that portion of the nongovernment mobile service which has been specifically allocated the authorized frequency (or frequencies) of the developmental land station.

Developmental mobile station. A mobile station operated for the express purpose of developing equipment or a technique solely for use only in that portion of the non-Government mobile service which has been specifically allocated the authorized frequency (or frequencies) of the developmental mobile station.

Developmental radiodetermination station. A radiodetermination station operated for the express purpose of developing equipment or a technique solely for use only in that portion of the nongovernment radiodetermination service (including the nongovernment radionavigation service) which has been specifically allocated the authorized frequency (or frequencies) of the developmental radiodetermination station.

Specific classification. The specific classes of developmental stations on land licensed in the maritime mobile service, the maritime radiodetermination service (including maritime radionavigation service), and the maritime fixed services, are the same as the particular class of station followed by the parenthetical indicator "(developmental)", for example: "Public class III coast station (developmental)".

F. OPERATIONAL

Business communication. Radiocommunication pertaining to economic, commercial, or governmental matters related directly to the purposes for which a ship is being used.

Calling. Transmission from a station solely to secure the attention of another station, or other stations, for a particular purpose.

Control point. An operating position associated with a particular station or stations which is: (1) Under the control and supervision of the station licensee or his authorized agent; and (2) A place at which the required monitoring and control facilities are available; and (3) A place at which a duly licensed operator (or other person if the requirement for a licensed operator is waived by the Commission) responsible for the operation of the transmitter(s) is stationed.

Dispatch point. A place from which radiocommunication may be transmitted under supervision of a responsible operator at a control point.

Distress signal. (1) The distress signal is the international radiotelegraph or radiotelephone signal which indicates that a ship, aircraft, or other vehicle is threatened by grave and imminent danger and requests immediate assistance. (2) In radiotelegraphy, the international distress signal consists of the group "three dots, three dashes, three dots", transmitted as a single signal in which the dashes are emphasized so as to be distinguished clearly from the dots. (3) In radiotelephony, the international distress signal consists of the oral enunciation of the word "Mayday", pronounced as the French expression "m'aider". In case of distress, transmission of this particular signal is intended to insure recognition of a radiotelephone distress call by stations of any nationality.

Distress traffic. All messages relative to the immediate assistance required by the ship, aircraft, or other vehicle in distress.

500 kilocycles silent period. The three-minute period twice an hour beginning at x h 15 and x h 45, Greenwich mean time (GMT), during which the International Radio Regulations require that all transmissions (except for certain emissions designated in those Regulations) must cease on all frequencies within a designated frequency-band centered on 500 kc/s.

Operational communication. Radiocommunication concerning the navigation, movement, or management of a ship or ships. (1) **Navigation.** This includes the piloting of a vessel. (2) Movement. This includes information and necessary communications relative to when and where the boat or ship will move or be moved as, for example, rendezvous at a port, basin, or marina, or for maneuvers during a cruise. (3) Management. This includes the obtaining of necessary supplies for the ship, limited to immediate needs, and the scheduling of repairs or modifications to the ship, limited to communications with those directly involved in the repairs or modification or concerned with changes in the movement of the ship because of those repairs or modifications.

Port operations. Communications in or near a port, or in locks or waterways, between coast stations and ship stations, or between ship stations, in which messages are restricted to those relating to the movement and safety of ships and, in emergency, to the safety of persons.

Safety communication. The transmission or reception of distress, alarm, urgency, or safety signals, or any communication preceded by one of these signals, or any form of radiocommunication which, if delayed in transmission or reception, may adversely affect the safety of life or property.

Safety signal. (1) The safety signal is the international radiotelegraph or radiotelephone signal which indicates that the station sending this signal is ready to transmit a message concerning the safety of navigation or giving important meteorological warnings. (2) In radiotelegraphy, the international safety signal consists of three repetitions of the group "TTT", sent before the call, with the letters of each group and the successive groups clearly separated from each other. (3) In radiotelephony, the international safety signal consists of three oral repetitions of the French word "Securite", sent before the call.

Superfluous radiocommunication. Any transmission that is not necessary in properly carrying on the service for which the station is licensed.

Urgency signal. (1) The urgency signal is the international radiotelegraph or radiotelephone signal which indicates that the calling station has a very urgent message to transmit concerning the safety of a ship, aircraft, or other vehicle, or of some person on board or within sight. (2) In radiotelegraphy, the international urgency signal consists of three repetitions of the group "XXX", sent before the call, with the letters of each group and the successive groups clearly separated from each other. (3) In radiotelephony, the international urgency signal consists of three oral repetitions of the word "Pan" pronounced as the French word "panne" and sent before the call.

Watch. The act of listening on a designated frequency.

Working. Radiocommunication carried on, for a purpose other than calling, by any station or stations using telegraphy, telephony, or facsimile.

VII Aviation Services

Aeronautical advisory station. An aeronautical station used for advisory and civil defense communications primarily with private aircraft stations.

Aeronautical enroute station. An aeronautical station carrying on a service with aircraft stations, but which may also carry on a limited communication service with other aeronautical enroute stations.

Aeronautical fixed service. A fixed service intended for the transmission of information relating to air navigation, preparation for and safety of flight.

Aeronautical fixed station. A station in the aeronautical fixed service.

Aeronautical metropolitan station. An aeronautical station used for communication with aircraft, including helicopters, operating between a main air terminal of a metropolitan area and subordinate landing areas.

Aeronautical mobile service. A mobile service between aeronautical stations and aircraft stations, or between aircraft stations, in which survival craft stations may also participate.

Aeronautical multicom land station. An aeronautical station operating in the aeronautical multicom service.

Aeronautical multicom mobile station. A mobile station operating in the aeronautical multicom service.

Aeronautical multicom service. A mobile service not open to public correspondence, used to provide communications essential to conduct of activities being performed by or directed from private aircraft.

Aeronautical public communication service. A communication service carried on between aircraft and land radio stations for the purpose of providing a public communication service for persons aboard aircraft.

Aeronautical public service station. A radio station, ground or aircraft, operated in the aeronautical public communication service.

Aeronautical radionavigation service. A radio navigation service intended for the benefit of aircraft.

Aeronautical search and rescue station. A land or mobile station in the aeronautical mobile service used for communication with aircraft and other aeronautical search and rescue stations pertaining to search and rescue activities with aircraft.

Aeronautical station. A land station in the aeronautical mobile service. In certain instances an aeronautical station may be placed on board a ship.

Aeronautical telemetering land station. A telemetering mobile station used in the flight testing of manned or unmanned aircraft, missiles, or major components thereof.

Aeronautical telemetering mobile station. A telemetering mobile station used in the flight testing of manned or unmanned aircraft, missiles, or major components thereof.

Aeronautical utility land station. A land station located at airdrome control towers and used for control of ground vehicles and aircraft on the ground at airdromes.

Aeronautical utility mobile station. A mobile station used for communication, at airdromes, with the aeronautical utility land station, ground vehicles, and aircraft on the ground.

Air carrier aircraft station. An aircraft station aboard an aircraft engaged in or essential to, transportation of passengers or cargo for hire. For the purpose of the rules in this part an aircraft weighing less than 10,000 lbs. may be considered at the option of the applicant, as a private aircraft even though actually engaged in air carrier operations. The election by the applicant will determine the equipment and frequencies to be employed and the regulations applicable to the aircraft radio station.

Aircraft station. A mobile station in the aeronautical mobile service on board an aircraft.

Airdrome control station. An aeronautical station providing communication between an airdrome control tower and aircraft.

Aviation instructional station. A land or mobile station in the aeronautical mobile service used for radiocommunications pertaining to instructions to students or pilots while actually operating aircraft or engaged in soaring activities.

Aviation services. Aviation services are primarily for the safe, expeditious and economical operation of the aircraft. They include the aeronautical fixed service, aeronautical mobile service, aeronautical radionavigation service, and secondarily, the handling of public correspondence to and from aircraft.

Civil Air Patrol Land Station. A land station used exclusively for communications of the Civil Air Patrol.

Civil Air Patrol Mobile Station. A mobile station used exclusively for communications of the Civil Air Patrol.

Earth-space service. A radiocommunication service between earth stations and space stations.

Earth Station. A station in the earth-space service located either on the earth's surface or on an object which is limited to flight between points on the earth's surface.

Flight test aircraft station. An aircraft station aboard an aircraft used for the transmission of essential communications in connection with the tests of aircraft or major components of aircraft.

Flight test station. An aeronautical station used for the transmission of essential communications in connection with the testing of aircraft or major components of aircraft: Provided, however, flight test stations, when operating on the frequency 3281 kc/s, are designated as land stations, only with respect to operation on the frequency 3281 kc/s.

Glide path station. A directional radio beacon associated with an instrument landing system which provides guidance in the vertical plane to an aircraft for the purpose of approach in landing.

Ground radio station. Any radio station on the ground equipped or engaged in radiocommunication or radio transmission of energy.

Instrument landing system. A radionavigation system which provides aircraft with horizontal and vertical guidance just before and during landing and, at certain fixed points, indicates the distance to the reference point of landing.

Instrument landing system glide path. A system of vertical guidance embodied in the instrument landing system which indicates the vertical deviation of the aircraft from its optimum path of descent.

Instrument landing system localizer. A system of horizontal guidance embodied in the instrument landing system which indicates the horizontal deviation of the aircraft from its optimum path of descent along the axis of the runway.

Landing area. Any locality, either land or water, including airports and intermediate landing fields, which is used, or intended to be used, for the landing and take-off of aircraft, whether or not facilities are provided for shelter, servicing, or repair of aircraft, or for receiving or discharging passengers or cargo.

Localizer station. A radionavigation land station in the aeronautical radionavigation service which provides signals for the lateral guidance of aircraft with respect to a runway center line.

Marker beacon. A transmitter in the aeronautical radionavigation service which radiates vertically a distinctive pattern for providing position information to aircraft.

Marker beacon station. An aeronautical radionavigation land station employing a marker beacon.

Omni-directional range station. A radionavigation land station in the aeronautical radionavigation service providing direct indication of the bearing (omni-bearing) of that station from an aircraft.

Private aircraft station. An aircraft station on board an aircraft not operated as an air carrier.

Public correspondence. Any telecommunication which the offices and stations must, by reason of their being at the disposal of the public, accept for transmission.

Radio altimeter. A radionavigation equipment, on board an aircraft, which makes use of the reflection of radio waves from the ground to determine the height of the aircraft above the ground. (For the purpose of this definition, "ground" refers to the surface of the earth.)

Radionavigation land test station (MTF). A radionavigation land station (Maintenance Test Facility) in the aeronautical radionavigation service which is used as a radionavigation calibration station for the transmission of essential information in connection with the testing and calibration of aircraft navigational aids, receiving equipment, and interrogators at predetermined surface locations. The primary purpose of this facility is to permit maintenance testing by aircraft radio service personnel.

Radionavigation land test station (OTF). A radionavigation land station (Operational Test Facility) in the aeronautical radionavigation service which is used as a radionavigation calibration station for the transmission of essential information in connection with the testing and calibration of aircraft navigational aids, receiving equipment, and interrogators at predetermined surface locations. The primary purpose of this facility is to permit the pilot to check a radionavigation system aboard the aircraft prior to takeoff.

***Space station.** A station in the earth-space service or the space service located on an object which is beyond, or intended to go beyond, the major portion of the earth's atmosphere and which is not intended for flight between points on the earth's surface.

Surveillance radar station. A radionavigation land station in the aeronautical radionavigation service employing radar to display the presence of aircraft within its range.

VIII Public Safety Radio Services

Fire Radio Service. A public safety service of radiocommunication essential to official fire activities.

Forestry-Conservation Radio Service. A public safety service of radiocommunication essential to forestry-conservation activities.

Highway Maintenance Radio Service. A public safety service of radiocommunication essential to official highway activities.

Interzone station. A fixed station in the Police Radio Service using radiotelegraphy (A1 emission) for communication with zone stations within the zone and with interzone stations in other zones.

Local Government Radio Service. A service of radiocommunication essential to official activities of states, possessions, and territories, including counties, towns, cities, and similar governmental subdivisions.

Police Radio Service. A public safety service of radiocommunication essential to official police activities.

Public safety radio services. Any service of radiocommunication essential either to the discharge of non-Federal government functions or the alleviation of an emergency endangering life or property, the radio transmitting facilities of which are defined as fixed, land, mobile, or radiolocation stations.

Safety service. A radiocommunication service used permanently or temporarily for the safeguarding of human life and property.

Special Emergency Radio Service. A public safety service of radiocommunication essential to the alleviation of an emergency endangering life or property.

State Guard Radio Service. A public safety service of radiocommunication essential to official activities of state guards or comparable organizations of states, territories, possessions, or the District of Columbia.

Zone station. A fixed station in the Police Radio Service using radiotelegraphy (A1 emission) for communication with other similar stations in the same zone and with an interzone station.

IX Industrial Radio Services

Community antenna television systems. The term "community antenna television system" ("CATV system") means any facility which, in whole or in part, receives directly or indirectly over the air and amplifies or otherwise modifies the signals transmitting programs broadcast by one or more television stations and distributes such signals by wire or cable to subscribing members of the public who pay for such service, but such term shall not include (1) any such facility which serves fewer than 50 subscribers, or (2) any such facility which serves only the residents of one or more apartment dwellings under common ownership, control, or management, and commercial establishments located on the premises of such an apartment house.

Distant signal. The term "distant signal" means the signal of a television broadcast station which is extended or received beyond the Grade B contour of that station.

Grade A and Grade B contours. The terms "Grade A contour" and "Grade B contour" means the field intensity contours.

Independent station. The term "independent station" means a television station which is not affiliated with any national television network organization.

Network programing. The term "network programing" means the programing supplied by a national television network organization.

Principal community contour. Signal contour which a television station is required to place over its entire principal community.

Substantially duplicated. The term "substantially duplicated" means regularly duplicated by the network programing of one or more other stations, singly or collectively, in a normal week during the hours of 6 to 11 p.m., local time, for a total of 14 or more hours.

X Land Transportation Radio Services

Automobile Emergency Radio Service. The term "Automobile Emergency Radio Service" as used in this part means a radiocommunication service for use in connection with the dispatching of emergency road service vehicles for the purpose of providing assistance to disabled automotive vehicles used on streets or highways.

Common carrier. As used in the Motor Carrier Radio Service, a person who holds himself out to the general public to engage in the transportation of passengers or property without discrimination, for compensation as a regular occupation or business.

Contract carrier. As used in the Motor Carrier Radio Service, a person who under individual contracts or agreements engages in the transportation of passengers or property for compensation as a regular occupation or business.

Land transportation radio services. Any private service of radiocommunication essential to the conduct of certain land transportation activities, the transmitting facilities of which are defined as fixed, land, mobile or radiolocation stations.

Mobile relay station. A base station in the mobile service, authorized primarily to retransmit automatically on a mobile service frequency, communications originated either by associated mobile units or by an associated control station. (Authorized in the Railroad Radio Service only.)

Mobile Repeater station. A mobile station in the mobile service, authorized to retransmit automatically on a mobile service frequency, communications originated either by associated pack-carried or hand-carried mobile units or by other mobile or base stations directed to such pack-carried or hand-carried units. (Authorized in the Railroad Radio Service only.)

Motor carrier. Any streetcar, bus, truck, or other land motor vehicle operated over public streets or highways by a common or contract carrier and used for the transportation of passengers or property (freight) for compensation: Provided, however, that motor vehicles used as taxicabs, livery vehicles, or school buses, and motor vehicles used for sightseeing or special charter purposes, shall not be included within the meaning of this term as used in the Motor Carrier Radio Service.

Motor Carrier Radio Service. A radiocommunication service for use in connection with the operation of a motor carrier land transportation system.

Railroad Radio Service. Radiocommunication service for use in connection with the operation and maintenance of a railroad common carrier.

Taxicab **Radio Service.** The term "Taxicab Radio Service", as used in this part means a radiocommunication service for use in connection with the transportation facilities of a taxicab common carrier.

Urban area. As used in the Motor Carrier Radio Service, one or more contiguous, incorporated or unincorporated cities, boroughs, towns, or villages, having aggregate population of 2,500 or more persons.

XI Citizens Radio Service

Citizens Radio Service. A radiocommunications service of fixed, land, and mobile stations intended for short-distance personal or business radiocommunications, radio signaling, and control of remote objects or devices by radio; all to the extent that these uses are not specifically prohibited in this part.

Class A station. A station in the citizens Radio Service licensed to be operated on an assigned frequency in the 460-470 mc/s band and with input power of 60 watts or less.

Class B station. A station in the Citizens Radio Service licensed to be operated on an authorized frequency in the 460-470 mc/s band and with input power of 5 watts or less.

Class C station. A station in the Citizens Radio Service licensed to be operated on an authorized frequency in the 26.96-27.23 mc/s band, or on the frequency 27.255 mc/s, for the control of remote objects or devices by radio, or for the remote actuation of devices which are used solely as a means of attracting attention, or on an authorized frequency in the 72-76 mc/s band for the control of model aircraft only.

Class D station. A station in the Citizens Radio Service licensed to be operated on an authorized frequency in the 26.96-27.23 mc/s band or on the frequency 27.255 mc/s, with input power of 5 watts or less, and for radiotelephony only.

Remote control. The term "remote control" when applied to the use or operation of a citizens radio station means control of the transmitting equipment of that station from any place other than the location of the transmitting equipment, except that direct mechanical control or direct electrical control by wired connections of transmitting equipment from some other point on the same premises, craft or vehicle shall not be considered to be remote control.

XII Amateur Radio Service

Amateur mobile station. An amateur station that is so constructed that it may conveniently be transferred to or from a mobile unit or from one such unit to another, and is ordinarily used while such mobile unit is in motion.

Amateur operator. A person interested in radio technique solely with a personal aim and without pecuniary interest, holding a valid license issued by the Federal Communications Commission authorizing him to operate licensed amateur stations.

Amateur portable station. An amateur station that is so constructed that it may conveniently be moved about from place to place for communication, but which is not operated while in motion.

Amateur radiocommunication. Radiocommunication between amateur stations solely with a personal aim and without pecuniary interest.

Amateur service. A radio service carried on by amateur stations.

Amateur station. A station used by an amateur operator, and embracing all radio transmitting apparatus at a particular location used for amateur service and operated under a single instrument of authorization.

XIII Disaster Communications Service

Associated station. A disaster station is considered to be associated with a licensed station in some other service when both stations are licensed to the same licensee at the same location and both stations are included in at least one coordinated disaster communications plan of the area concerned. A portable station or a mobile station in the Disaster Communications Service will be considered to be associated with the station in the other service which is located at its base of operations.

Competent local authority. That authority within a community or larger area which is so designated in the coordinated disaster communications plan for the area concerned, including any alternate authority who may be so designated in such plan. In the absence of the specifically designated authority, the individual in charge of the net control station, or his representative, for the organized disaster station network established in accordance with the coordinated disaster communications plan, shall be considered as competent authority for the activation of the stations of that network. Duly designated civil defense officials will be considered competent local authority in the organization or operation of disaster communications radio networks and stations, and in the coordination of disaster communications plans.

Disaster. An occurrence of such nature as to involve the health or safety of a community or large area, or the health or safety of any group of individuals in an isolated area to whom no normal means of communications are available, and include, but are not limited to, floods, earthquakes, hurricanes, explosions, aircraft or train wrecks, and consequences of armed attack.

Disaster communications. Communications essential to the establishment and maintenance of communication channels to be used in connection with disasters or other incidents involving loss of communications facilities normally available or which demand the temporary establishment of communications facilities beyond those normally available, including communications necessary or incidental to drills and simulated disaster relief activity on the part of persons or organizations participating in the use of such communication channels; or communications or signals essential to the public welfare, or that of any segment of the public, including communications directly concerning safety of life, preservation of property, maintenance of law and order, and alleviation of human suffering and need, in the case of any actual or imminent disaster or other such incident.

Disaster Communications Service. A service of fixed, land, and mobile stations licensed, or authorized, to provide essential communications incident to or in connection with disasters or other incidents which involve loss of communications facilities normally available or which require the temporary establishment of communications facilities beyond those normally available.

Disaster station. Any government or nongovernment radio station able to function as a fixed, land, or mobile station and authorized, if government, by its controlling federal government agency or licensed, if nongovernment, by the Federal Communications Commission to operate in the Disaster Communications Service. A single disaster station may consist of more than one unit, each capable of being operated independently as a fixed, land, or mobile station.

Portable station. A land station in the Disaster Communications Service which is capable of being moved from place to place and is in fact, from time to time, moved to and operated at unspecified fixed locations for the purpose of communicating with other fixed, land, or mobile stations.

XIV Domestic Public Radio Services

Auxiliary test station. A fixed station used for test transmissions only, operating on mobile station frequencies from a specified fixed location, for the purpose of determining the performance of fixed receiving equipment which is remotely located from the base station with which it is associated, or where the receiving equipment is located with the base station and both are remotely located from the control point of the station.

Central office. A landline termination center used for switching and interconnection of public message communication circuits.

Central office station. A fixed station used for transmitting communications to rural subscriber stations associated therewith.

Domestic fixed public service. A fixed service, the stations of which are open to public correspondence, for radiocommunication between points all of which lie within: (a) the State of Alaska, or (b) the State of Hawaii, or (c) the remaining 48 states and the District of Columbia, or (d) a single possession of the United States.

Domestic public land mobile radio service. A public communication service for hire between land mobile stations wherever located and their associated base stations which are located within the United States or its possessions, or between land mobile stations in the United States and base stations in Canada.

Domestic public radio service. The land mobile and domestic fixed public services the stations of which are open to public correspondence.

Effective radiated power. The product of the antenna power input and the antenna power gain. This product should be expressed in watts. (If specified for a particular direction, effective radiated power is based on the antenna power gain in that direction only.)

Exchange. A unit of a communication company or companies for the administration of communication service in a specified area, which usually embraces a city, town, or village and its environs, and consisting of one or more central offices, together with the associated plant, used in furnishing communication service in that area.

Exchange area. The geographic area included within the boundaries of an exchange.

Fixed microwave auxiliary station. A fixed station used in connection with (1) the alignment of microwave transmitting and receiving antenna systems and equipment, (2) coordination of microwave radio survey operations, and (3) cue and contact control of television pickup station operations.

Frequency tolerance. The frequency tolerance, expressed as a percentage or in cycles per second, is the maximum permissible deviation, with respect to the reference frequency of the corresponding characteristic frequency of an emission.

General communication. Two-way voice communication, through a base station, between a common carrier land mobile station and a landline telephone station connected to a public message landline telephone system, or between two common carrier land mobile stations via a base station.

Inter-office station. A fixed station in the domestic fixed public service which is used exclusively for interconnection of telephone central offices.

Local television transmission service. A domestic public radiocommunication service for the transmission of television material and related communications.

Message center. The point at which messages from members of the public are accepted by the carrier for transmission to the addressee.

Microwave frequencies. As used in this part, this term refers to frequencies of 890 mc and above.

Miscellaneous common carriers. Communications common carriers which are not engaged in the business of providing either a public landline message telephone service or public message telegraph service.

Mobile microwave auxiliary station. A mobile station used in connection with (1) the alignment of microwave transmitting and receiving antenna systems and equipment, (2) coordination of microwave radio survey operations, and (3) cue and contact control of television pickup station operations.

Point-to-point microwave radio service. A domestic public radio service rendered on microwave frequencies by fixed stations between points which lie within the United States or between points in its possessions or to points in Canada or Mexico.

Private line service. A service whereby facilities for communication between two or more designated points are set aside for the exclusive use or availability for use of a particular customer and authorized users during stated periods of time.

WHY DO YOU WANT TO SUCCEED?

There are several answers to this question. You may want to succeed for the very human reason that you want more money with which to enjoy life, or you may have a family for whom you want to provide those comforts they so well deserve -- a home, a new car, good clothes, life insurance, and financial security.

Your ambition to succeed may be prompted by the desire to bring happiness to an aged father, mother, or relative whose chief hope in life is to see you enjoy prosperity and prestige, to see you on the pinnacle of success.

Pause for just a minute and think -- what is your reason for wanting success? With this reason in mind, resolve firmly that you will never allow your ambition to weaken. Resolve that you will never swerve from the direct path of your goal. Make this resolution now and keep it, so the years to come will be happier and more prosperous for you.

John F. Thompson

Innovation in learning
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ACHIEVEMENT THROUGH ELECTRONICS

nri

TRAINING KIT MANUAL

1T

NATIONAL RADIO INSTITUTE • WASHINGTON, D. C.

TRAINING KIT MANUAL 1T

PRACTICAL DEMONSTRATIONS
IN BASIC ELECTRONICS

A Plan For Studying The Experiments

As you know, these Experimental Kits are intended to come to you on a definite schedule. This arrangement is so that you will study the necessary theory in your regular lessons before you carry out any corresponding experiments. This permits you to adopt either of the following plans of study:

1. You may wish to complete one or two experiments in a kit, do a lesson, and then return to the kit for one or two more experiments. This plan permits the experiments in one kit to be finished about the time the next kit is due. Thus, the lessons and experiments run along together, and provide you with a varied program of study.
2. You may prefer to break away from your lessons and to complete all the experiments in a kit at one time before going back to your lessons. This plan has the advantage that you do not waste any time getting out and putting away materials, but it can be followed only if you can leave your equipment set up long enough to finish.

Whichever plan you follow, you can begin NOW with the experiments in this kit. However, be sure to read the preliminary information on pages one through sixteen before you begin, so you will know just how the experiments are to be carried out. In a similar manner, begin on future kits as soon as you receive them.

NOTICE

NRI has set up the CONAR Division of the National Radio Institute to handle the sale of professional test equipment and other electronic equipment. NRI has had unsurpassed experience in the design of quality kits. All CONAR kits are designed and produced by the National Radio Institute. The transistorized volt-ohmmeter you will build as part of your training is the CONAR Model 212. This is the same professional tvom you will see advertised nationwide. Several of the parts you received in this kit, including the meter, will be used in the assembly of your tvom.

KL10M671 1973 EDITION Litho in U.S.A.

INSTRUCTIONS FOR PERFORMING EXPERIMENTS 1 THROUGH 10

LECTURE-ROOM DEMONSTRATIONS YOU PERFORM IN YOUR OWN HOME

How many times have you heard the expression, "Seeing is believing"? Probably many times, because it is human nature to doubt something you cannot see or touch.

Although you can learn how a piece of equipment works from pictures and words, the average person understands better if he can actually set up equipment and make tests himself to see how it works.

You must have a knowledge of theory before you can work successfully in the radio-TV-electronics field. However, unless you know how to apply theory and make tests, your knowledge is useless. Theory and practical application must go hand-in-hand.

The NRI Course of training is a well-balanced combination of theory and practical instruction. Practical demonstrations and experiments are given in this manual and the following manuals.

Doing these experiments will give you actual experience in handling parts and making measurements, and will help you understand explanations of more advanced circuit actions. This type of experience is more valuable to you than class or lecture-room demonstrations by an instructor in which you take no active part, and you can do the experiments at your own convenience.

This practical work with experimental equipment will help you develop confidence in your own ability and will provide what you need to become a practical technician.

The experiments will help you to solve technical problems you will encounter in your work. You will see for yourself what happens when a particular part is defective, and you will learn how to detect and correct errors and how to adjust circuits.

Every experiment in every manual is important, because it is an actual working demonstration. Do not pass over any of them hurriedly, even though you may feel that you already know the results.

If you look underneath the chassis of any modern piece of electronic equipment, you will see that the connections are soldered. A soldered connection is the most reliable type of connection to make in commercial production because it will not deteriorate much during the entire life of the electronic equipment.

When you repair defective equipment, you must be able to find the defective stage and then the defective part. However, the ability to find what is wrong is of little use unless you also know how to take out the defective part and how to solder the connections for a new part. Furthermore, you may often have to unsolder one or more connections during your tests in order to find the defective part.

In the first section of this manual, you will study the fundamentals of soldering and learn how to make a good soldered connection using actual electronic parts. You will make these connections in ex-

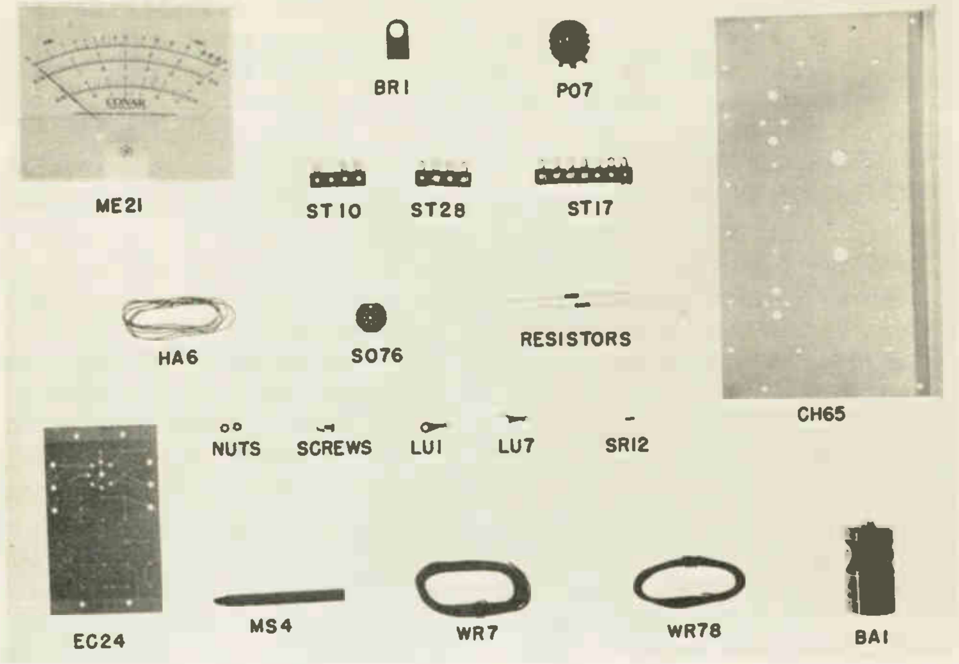


Fig. 1. Parts used in this Experimental Manual are shown here and listed below.

Quan.	Part No.	Description	Price Each
2	BA1	Size D flashlight cell	.20
1	BR1	Pot mounting bracket	.05
1	CH65	Chassis plate	.93
1	EC24	Etched circuit board	1.10
1	HA6	Solder	.41
1	LU1	Solder lug, small	12/.15
2	LU7	Solder lug, large	12/.15
1	ME21	Meter	10.92
1	MS4	Marking crayon	.05
6	NU1	6-32 hex nut	12/.15
2	NU5	4-40 hex nut	12/.15
1	PO7	1000-ohm pot w/lockwasher/nut	.75
1	RE28*	470-ohm resistor	.15
2	RE29	4700-ohm resistor	.15
3	RE30	1000-ohm resistor	.15
2	RE33	22,000-ohm resistor	.15
2	RE36	100,000-ohm resistor	.15
1	RE50	6800-ohm resistor	.15
1	RE52	82,000-ohm resistor	.15
2	RE56	680-ohm resistor	.15
1	RE165	15,000-ohm, 5% resistor	.24
6	SC1	1/4″ X 6-32 machine screw	12/.15
2	SC6	1/4″ X 4-40 machine screw	12/.15
1	SO76	7-pin tube socket	.12
2	SR12	Silicon diode	.67
1	ST10	3-lug terminal strip	.05
1	ST17	7-lug terminal strip	.12
1	ST28	4-lug terminal strip	.10
1	WR7	25′ red hookup wire	.50
1	WR78	6′ black hookup wire	.12

*All resistors are 1/2-watt, 10% tolerance unless otherwise specified.

actly the same way that you would in working on commercial equipment. The solder, hookup wire, and other parts that are included in this kit are standard items, just like those that you might use in working on any piece of electronic equipment. In later experiments, you will have practice in working from schematic diagrams. You will also assemble a number of simple circuits to demonstrate some basic electrical laws.

HOW THE MANUALS ARE ARRANGED

The manual for each kit in your Practical Demonstration Course contains the instructions for performing ten experiments. These experiments are numbered consecutively throughout the whole series; Experiments 1-10 are in the first manual, 11-20 in the second, etc. At the end of each experiment is a Statement that you are to complete, so that you can check your work as you go along. When the ten statements have been answered, be sure to submit the training Kit Report to NRI for grading.

In each manual, the figures are numbered to correspond to each experiment. Each figure number has two parts. The first part is the number of the experiment in which it appears, and the second part is the number of the figure within the experiment. For example, Fig. 1-3 would be the third figure in Experiment 1; Fig. 6-2 would be the second figure in Experiment 6. If there are any figures that do not apply to one particular experiment, they will be numbered consecutively in each manual, starting with Fig. 1.

CONTENTS OF THIS KIT

The parts included in your first kit are pictured in Fig. 1 and listed below. Each part that you receive in your kits is assigned a part number. The part number and description appears below Fig. 1. When you need a part for the experiments, you will be given the part value, a description, and in some cases the part number.

Now check the parts that you receive against this list to make certain that you have all of the parts. *Do not lose or discard any of these parts because you will use many of them again in later experiments.*

For your convenience, most of the parts are packed on cardboard under a clear plastic film. This protects the parts during shipment and also makes it easy to inventory your parts. To remove the parts, cut around them with a sharp knife or a razor blade.

IMPORTANT: If any part of this kit is obviously defective or has been damaged during shipment, please return the defective part to NRI for replacement, following the procedure given on the "Packing and Returned Material Slip" enclosed in this kit.

Preparing For The Experiments

Before you start the experiments, there are several things you will need to do. You will need a place to work and tools to work with.

You do not need an elaborate workbench. A folding card table set up near an electrical outlet will be satisfactory. Do not use a metal-top table, because it could cause short circuits that might damage the equipment. If you have to use a metal-top table, cover the top with a nonconductor, such as cardboard or linoleum.

TOOLS YOU WILL NEED

The tools you need to do these experiments are the same as those you will use in all kinds of electronic work. They are pictured in Fig. 2, and listed under the figure. None of these tools are supplied with this kit. Probably you already have some of these tools, since the average home usually does have a few tools for simple repair work.

You can get those tools you do not have from hardware stores, radio-supply

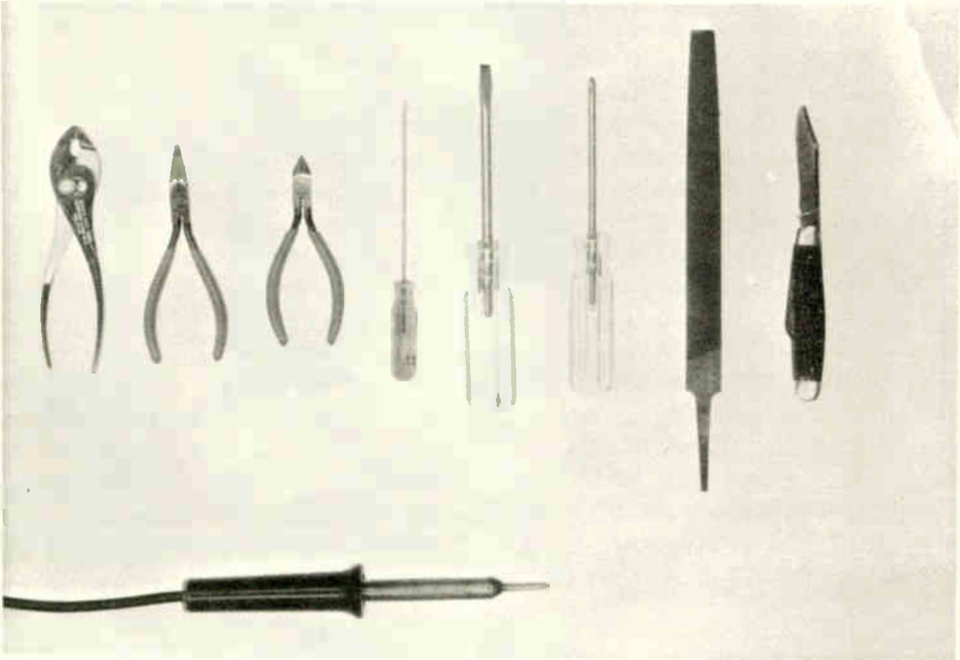


Fig. 2. These are the tools you will need to do these experiments. You probably already have many of them. Get the best ones you can afford; you will be using them throughout your course as well as when you do service work. These tools are not supplied with your kits. From left to right, all-purpose pliers, longnose pliers, diagonal cutters, small screwdriver, medium size screwdriver, Phillips screwdriver, metal-cutting file, and pocket knife. Below the tools is a soldering iron.

houses, or mail-order firms. Since you will use the tools in all of your electronic work, they are a worthwhile investment. Select good quality tools that "feel right" in your hand.

Pliers. The technician needs three types of pliers: longnose pliers, diagonal cutters, and ordinary slip-joint pliers. Each type has its own purpose and should be used for that purpose only. Pliers are designed primarily for holding, bending, and cutting. Many people use them for other purposes so they often ruin them or mar the material on which they are working.

Perhaps the pliers most often used in electronics are the longnose type. Although you may use longnose pliers to hold a nut in position so that it can be started on a screw, you should never use them to tighten nuts. You may spring the jaws so the points will not meet or you could actually break one of the jaws. Use your longnose pliers to hold wires in position for soldering, to remove wires, or for hard-to-reach places.

Diagonal cutting pliers, or "side cutters" as they are often called, are used for most cutting operations. Because the cutting jaws are at an angle, these pliers are ideal for cutting wires close to terminals.

Combination slip-joint pliers, often called "combination pliers," are also in common use. Because of the slip joint, the jaws can be opened wider at the hinge pin so that larger diameters can be gripped. These pliers come in 5, 6, 8, and 10-inch sizes. The thin-type, 6-inch size is best for electronics work.

Screwdrivers. Practically everyone is familiar with the standard screwdriver. The screwdriver is intended for one principal purpose - to loosen or tighten screws. Because the average person uses a screwdriver as a can opener, a pry or pinch bar, and even as a chisel, the screwdriver is one of the most abused tools.

The technician needs three screwdrivers - one with a small blade for loosening setscrews in dial and control knobs and one with a medium blade for general purpose work. He also needs a Phillips screwdriver because screws with a special head known as a "Phillips head" are often used in electronic equipment. Screwdrivers with plastic handles are best because the plastic is a good insulator. Later on you will need a special type of screwdriver, known as an "alignment tool." This is a non-metallic tool for special uses, but you won't need it now.

Files. There are more than twenty types of files. Each type comes in sizes from three to eighteen inches. They may be either single or double cut and are classified according to the different grades of coarseness or fineness, depending upon the size and spacing of the teeth.

The type most often used in electronics is a 10-inch second-cut mill file. It is used to keep the tip of the soldering iron in good condition by removing small amounts of metal, leaving the filed surface smooth. This type of file is also useful in brightening lugs for easier soldering.

Knife. A good knife is useful when preparing wires for connection to other parts; a sturdy pocket knife is fine.

Soldering Iron. The soldering iron is used more often by servicemen than any other tool. Since you will use it often and it is so important, you should choose it carefully. A number of soldering irons suitable for electronics work are shown in

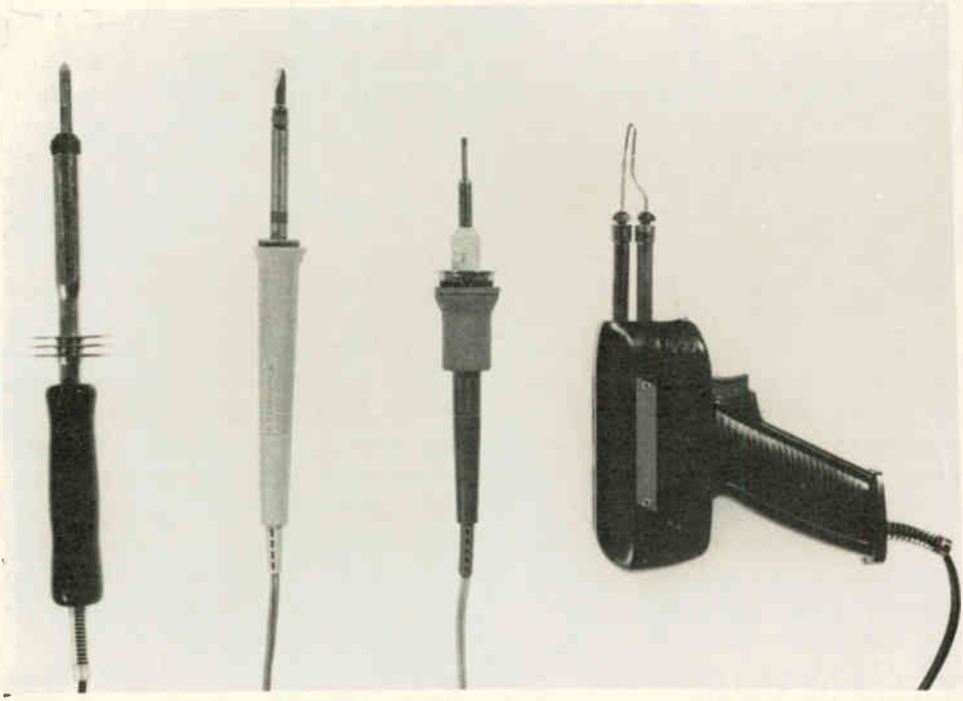


Fig. 3. Several soldering irons suitable for electronics work.

Fig. 3. It is best to buy a soldering iron from a firm that specializes in electronics parts. You should obtain your iron from your local wholesaler, from a mail-order wholesaler, or from the CONAR Instruments Division of NRI.

Hardware stores sometimes carry soldering irons in stock, but they may have only the large type that is used for heavy work, such as automobile radiator repair or roofing work. These irons are too heavy for easy handling and too big to be used where small parts are crowded together.

From left to right in Fig. 3, the first iron is called a medium duty iron. This type of iron generally has a rating of from 50 to 150 watts and is used where a relatively large amount of heat is needed, such as when soldering to the chassis.

The two irons in the center are "pencil" type irons. These types have replaceable heating elements and tips. They are available with various wattage ratings, usually 25 to 40 watts, suitable for general electronic soldering, and 40 to 50 watts, for heavier duty work. These "pencil" irons are the types most suitable for the beginner as they are lightweight and easy to handle. Perhaps the most suitable iron for the beginner would be one like the third iron from the left in Fig. 3. A 37-1/2 element and a chisel-shaped tip make an ideal choice of element and tip.

At the right in the photo is a soldering gun. A gun of this type has the advantage over the iron in that it heats and cools very quickly. Thus, it is excellent for a serviceman making house calls or a technician working on equipment in a plant. He plugs the gun in when he arrives at the job and it is ready for use immediately. Everyone going into electronics, whether on a part-time or full-time basis, will find a gun useful. However, it is not quite as easy to turn out well-soldered connections with a gun as it is with an iron. Therefore, the beginner should start with a conventional soldering iron and learn to use it correctly and later, if he so desires, he can use a soldering gun.

As mentioned previously, the most suitable single iron for general service work and for use in your kits is an electric iron with a tip about an inch long and 1/8" to 1/4" in diameter. The tip should be of the chisel type with two flat surfaces. The wattage rating should not be more than 50 watts, because a high-wattage iron is bulky, and if its barrel touches parts, it may damage them.

When you buy an iron, be sure you get a soldering iron stand with it, to rest the hot iron on when it is not in use. Or get an iron that is designed so that the handle is heavier than the tip end. Then the iron will balance when it is laid down with the tip off the bench.

The average electric soldering iron will operate on ac or dc at 117 volts. Power-line voltages may vary between 110 and 120 volts; an iron designed for 117-volt operation may be used on any voltage between 105 volts and 130 volts.

Although the modern soldering iron is a rugged tool, it should never be abused. Do not use it as a hammer, drop it, or attempt to cool it quickly by plunging it into water. When properly cared for, an iron will last for years.

Although some irons have pre-tinned tips, most tips must be tinned before use. If your iron has a bright, shiny tip or a dull gray tip, it has been pre-tinned, and it is ready for use. If the tip is a natural copper color, you must tin it before using it.

TINNING A SOLDERING IRON

You cannot solder properly unless your soldering iron is properly tinned. Therefore, your first step in learning how to solder is to learn how to tin a soldering iron.

The tip of the soldering iron is made of copper. When an untinned soldering iron is heated, the copper combines with the oxygen in the air, forming a dark coating of copper oxide on the tip of the iron. If you try to use an untinned iron, the copper oxide coating will act as a heat insulator and keep the heat of the iron from the parts you are trying to solder. It will be practically impossible to heat the part sufficiently to melt the solder properly.

You can prevent this by covering the tip of the iron with solder. This is called "tinning" the iron. The solder will form a protective layer over the copper tip so that the oxygen cannot get at the copper and corrode it. The tinned tip will be a good conductor of heat, and you will be able to heat the parts enough to solder them properly.

Preparing the Tip. The first step in tinning a soldering iron is to examine the tip. A photograph of the tip of a new soldering iron that has not been tinned is shown in Fig. 4A, and a photograph of a soldering iron that has been used and needs re-tinning is shown in Fig. 4B. Notice that the tip of the new iron is reasonably smooth, whereas the tip of the iron that has been used is pitted, dirty, and uneven.

If your soldering iron is in good condi-

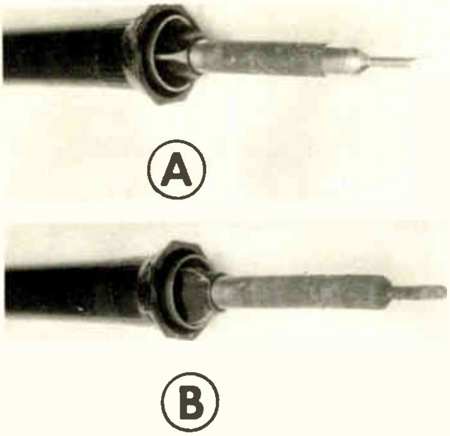


Fig. 4. If your soldering iron is new and has not been tinned as at (A), or if it has been used and is pitted as at (B), it will need tinning.

tion, like the one shown in Fig. 4A, you can plug it into an electrical outlet and start heating it. On the other hand, if you have an iron that has been used and looks like Fig. 4B, you should file the tip smooth before you start to heat it. Even though your iron may be in good condition, read the following instructions carefully, because after your iron has been used for some time, it will become pitted like the one shown in Fig. 4B. You will have to go through this procedure to re-tin it.

To file the tip of the iron, rest the iron on a vise or a similar metal support, as shown in Fig. 5. Grasp the iron in one hand and proceed to file one of the surfaces flat as shown. Try to file the surface at approximately the same angle as that of the original tip. Do not remove any more metal than is necessary, but make sure that you file the surface until all of the dark spots and holes in the surface are gone. When you have completed the operation, the tip of the iron should look as it does in Fig. 6.

After you have filed one surface of the tip, turn the iron over. In other words, rotate the iron 180°, and file the surface flat on the opposite side of the tip. Again, remove no more metal than is necessary, but make sure you file the surface until it is clean. Try to file at the same angle as the first surface, as shown in Fig. 7.

If your iron has a pyramid-shaped tip, turn the iron a quarter turn and file one of the other surfaces. Then turn the iron over and file the last surface. When you

Fig. 5. To file the tip of your iron, hold it against a vise as shown here.

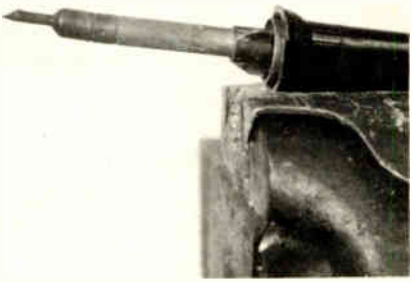


Fig. 6. When you have filed one surface, your iron should look like this.

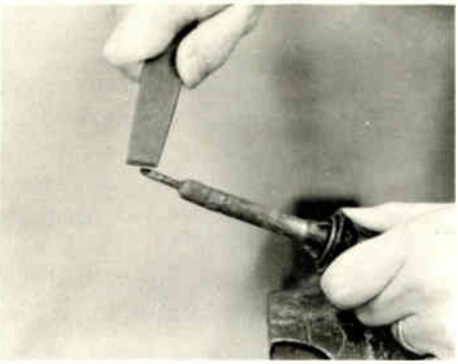


Fig. 7. File the opposite surface at the same angle as the first surface, as shown.

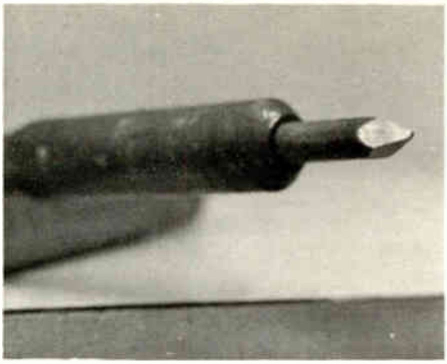


Fig. 8. Your iron should look like this after filing all four surfaces on its tip.

have filed all tip surfaces, the tip of the iron should look like the one shown in Fig. 8. Notice that the sides are approximately even.

Before you start to heat the iron, examine the edges of the flat surfaces on the tip. If the edges are rough, smooth them by careful rubbing with a piece of sandpaper.

Tinning the Iron. After you have prepared the surface for tinning, or if you are tinning a new iron that is in good condition, plug the iron in and wait for it to heat. As the iron heats, periodically touch the end of the solder to the tip so you will know when the iron is hot enough to melt the solder. You should tin it as soon as it reaches a high enough temperature, because the longer an untinned iron is heated, the more copper oxide will form on the tip.

When the iron has reached operating temperature, again rest it on a vise and lightly file one surface as shown in Fig. 5. Once you have filed the surface lightly so that it is shiny, quickly set the file down, pick up the roll of solder, and touch the end of the solder to the tip of the iron. Move the solder around the tip until the entire surface is tinned, as shown in Fig. 9. After you have tinned one surface of the tip, turn the iron and go through the same procedure of lightly filing the other surfaces, and then applying solder.

After you have tinned the surfaces of the tip, use a clean cloth to wipe off any excess solder. Hold the cloth loosely as shown in Fig. 10 to avoid burning your hand. When you have your iron tinned, it is ready for use. Unplug it, and set it aside until you are ready to start soldering.

Fig. 9. How to apply solder to tin the tip of the iron.

Fig. 10. Wiping excess solder from the iron with a piece of cloth.

Notice that the solder you received in this kit contains a rosin core that acts as a cleaning agent and prepares the metal surface to receive the solder. It is difficult to make a good soldered connection using plain solder alone; another material called flux must be applied along with the solder. Rosin flux is used in this case. Only rosin core solder should be used in soldering electronic equipment.

Hardware and other stores sell some solder with an acid core. Acid flux in any form should never be used in electronic equipment. The acid will corrode the leads and terminals and may damage some of the parts. Use only rosin core solder in electronics work; do not use liquid or paste flux. Solder similar to that which we have supplied in this kit should be used in all your electronics work.

IMPORTANT NOTICE

In checking students' problems, NRI has found that poor soldering is more frequently the cause of failure to get proper results than all other troubles combined. Therefore, be sure to perform every step in each experiment to learn all you can about soldering.

DO NOT SKIP ANY STEPS

MOUNTING THE PARTS

Most of your experiments will be carried out on your experimental chassis plate which is shown in the parts photo, Fig. 1. You will mount several parts on the chassis plate before you begin the experiments.

The parts supplied with this kit are shown in Fig. 1 and identified in the list below the photograph.

Gather the following parts and place them on your worktable. Then they will be handy when you are ready to use them:

1 Chassis plate (CH65)
1 7-lug terminal strip (ST17)
1 3-lug terminal strip (ST10)
1 4-lug terminal strip (ST28)
1 Potentiometer mounting bracket (BR1)
1 1K-ohm potentiometer (PO7)
1 Solder lug (LU1)
6 1/4" X 6-32 screws (SC1)
6 6-32 hex nuts (NU1)
1 Marking crayon (MS4)

Notice that we have supplied two sizes of screws and nuts. The size of a machine screw is given by its diameter and the number of threads per inch. The first number is the diameter. Thus, the 6-32 screws (SC1) are larger in diameter than the 4-40 screws (SC6), but the 4-40 screws have a finer thread. The length of a screw is given in fractions of an inch.

Follow the instructions as you mount the parts on your chassis and do not attach any parts until instructed to do so.

Place the chassis upright on your worktable so that the holes are positioned as shown in Fig. 11. The bent lip should be away from you and pointing upward. To

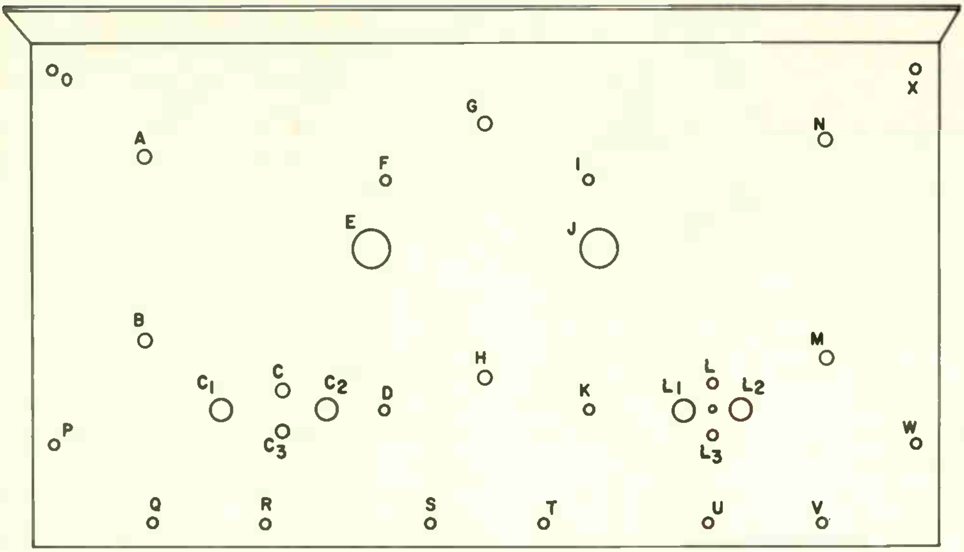


Fig. 11. Chassis hole identification.

help you locate the parts correctly, we have given the holes identifying letters. You can use the marking crayon to label these holes on the chassis. If you prefer, you can put small pieces of tape near these holes and mark on the tape with a pen.

Fig. 12 shows the chassis with the parts

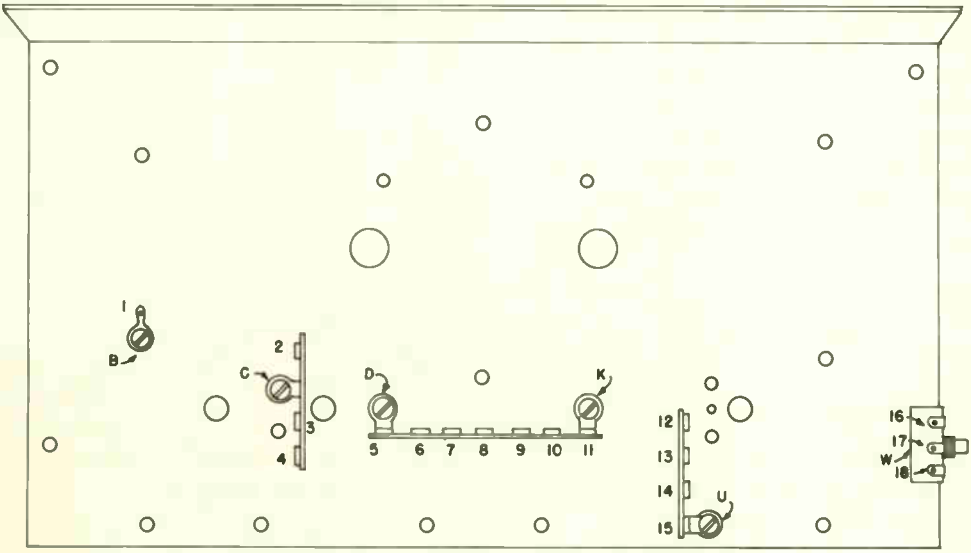


Fig. 12. Parts mounted on the chassis and the terminal identification number.

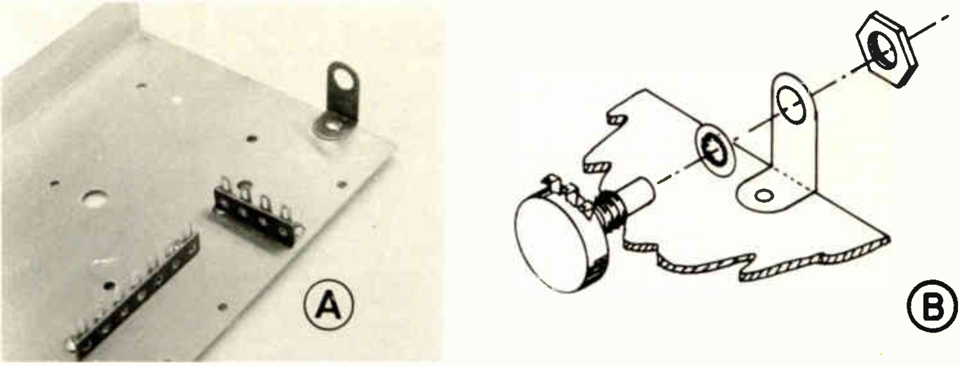


Fig. 13. (A) Mounting the potentiometer bracket; (B) mounting the potentiometer.

mounted on it. Be sure to mount the parts at the correct location and position them as shown in the drawing.

Mount the 3-lug terminal strip at hole C, as shown in Fig. 12. Pass a 1/4" X 6-32 screw down through the mounting foot in the terminal strip and through hole C in the chassis. Attach a 6-32 hex nut. Position the terminal strip as shown and tighten the screw. Hold the nut with pliers as you tighten the screw.

Install the 7-lug terminal strip at holes D and K. Use 1/4" X 6-32 screws and nuts. Position the strip exactly as shown in Fig. 12. Pass a screw down through the left mounting foot and hole D and attach a nut. Pass a screw through the other mounting foot and through hole K. Attach a nut and tighten both screws.

Mount the 4-lug terminal strip at hole U. Use a 1/4" X 6-32 screw and nut. Position the terminal strip as shown in Fig. 12 and tighten the screw.

Install the potentiometer mounting bracket at hole W. See Fig. 13A. Use a 1/4" X 6-32 screw and nut. Pass the screw down through the small mounting hole in the bracket and through hole W in the chassis. Attach the nut and tighten the screw.

Install the potentiometer in the potentiometer mounting bracket. As shown in Fig. 13B, slip the large lockwasher over the shaft and bushing of the potentiometer and slip the bushing through the hole in the bracket mounted on the chassis. Attach the large control nut, turn the potentiometer so its terminals are upward; then tighten the control nut.

Bend the solder lug at about a 45° angle, as shown in Fig. 14. Mount the solder lug at hole B, using a 1/4" X 6-32 screw and nut. Tighten the screw.

The numbers appearing in Fig. 12 are the terminal identification numbers. They will be used throughout this kit for identifying the terminals when making connections.

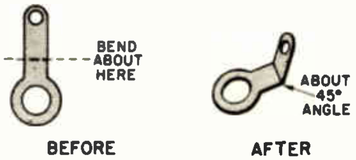


Fig. 14. Before you mount the solder lug, bend it as shown here.

Learning To Solder

Our experience in teaching students has shown that over 75% of the troubles encountered by students and technicians is due to poor soldering! You might think from this that good soldering is difficult, but this is not true. If you watch an experienced man work with a soldering iron, it looks quite simple. The experienced technician follows the two basic rules given below to make good soldering easy.

First: Have the materials to be joined and the tip of the iron clean and free from grease. If the terminals or wires are not bright, scrape them with a knife or with a piece of fine sandpaper until they are clean and bright.

Second: Have the sections to be joined hot enough to melt the solder so that it will run freely to all parts of the connection and form a good bond.

If you follow these two basic rules, you will never have soldering trouble. If you ignore them, you may spend hours looking for defective parts when the trouble is simply a poorly soldered connection.

SOLDERING TECHNIQUES

Perhaps the most important step in making a good soldered connection is to make sure that the parts you are attempting to solder together are clean. For example, if you try to solder a capacitor lead to a terminal strip, and the capacitor lead is not clean, you will find it practically impossible to get the solder to stick to the lead.

All leads, whether they are resistor or capacitor leads or merely wires to be soldered, should be tinned before you attempt to solder them. Most of the resistors and capacitors that you will receive in your kits have been tinned by the manufacturer. However, in the manufacturing processes, the tinned surface sometimes becomes covered with wax or other impurities. These leads should be cleaned and retinned whenever necessary.

You can use approximately the same procedure to tin a lead as you used to tin the tip of your soldering iron. The first step is to clean the lead. You can either scrape the lead carefully with a knife, as

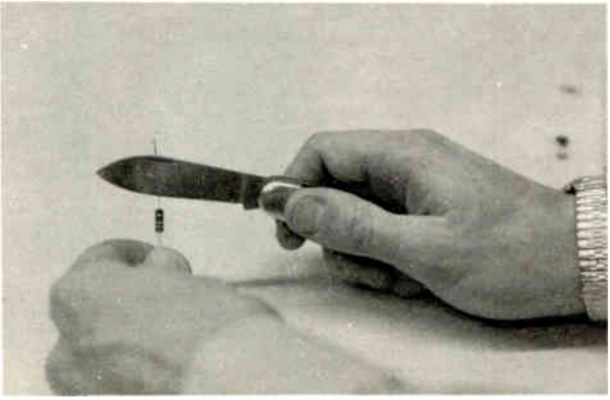


Fig. 15. How to use a knife to clean a resistor lead.

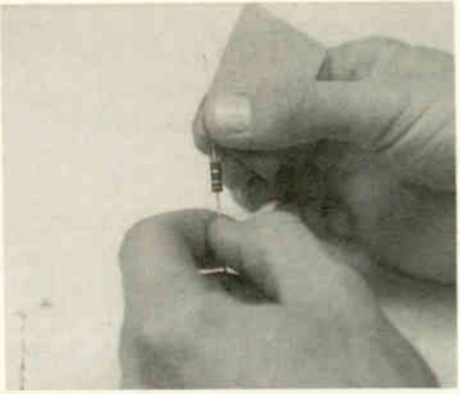


Fig. 16. Using sandpaper to clean a lead.

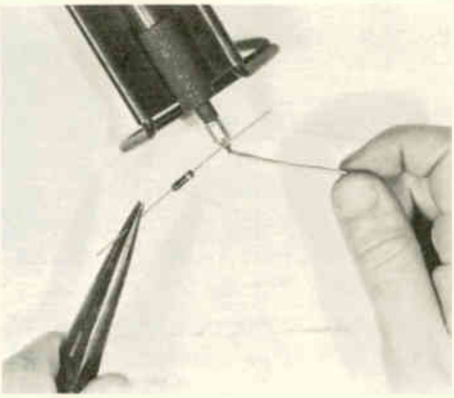


Fig. 17. How to tin a resistor lead.

shown in Fig. 15, or you can use a small piece of fine sandpaper. Hold the lead in the sandpaper, as shown in Fig. 16, and draw the sandpaper over the lead several times.

After you have cleaned the lead, hold the part with your longnose pliers and touch it to the tip of your soldering iron, as shown in Fig. 17. Then touch the solder to the lead. Allow a small amount of solder to melt onto the lead and onto the tip of the iron. Move the lead back and forth through the solder to tin the entire lead. If you apply enough heat to melt the solder thoroughly, the solder will flow smoothly over the lead, as shown in Fig. 18. Tin the other lead in the same way.

Lugs on terminal strips also should be cleaned and tinned before you attempt to solder a wire or a lead to the lug. Usually, brushing over the terminal quickly with a piece of sandpaper will remove any dirt or grease that may be on the terminal. Sometimes it will be necessary to scrape the terminal with a knife or file.

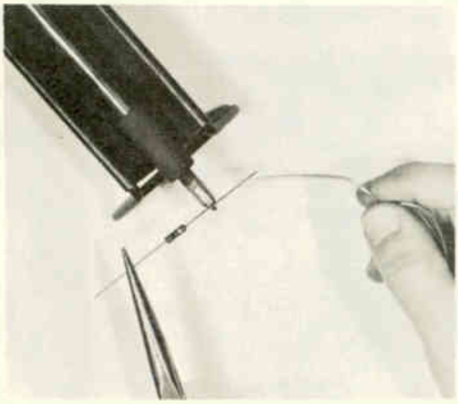


Fig. 18. A tinned resistor lead.

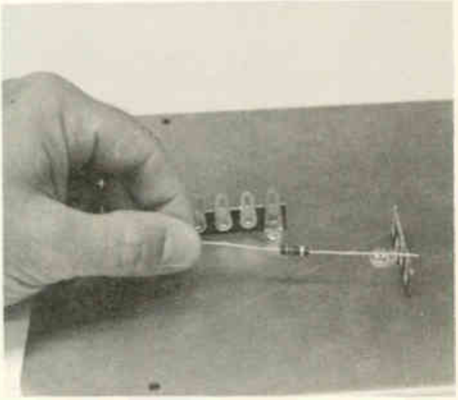


Fig. 19. Making a connection to terminal.

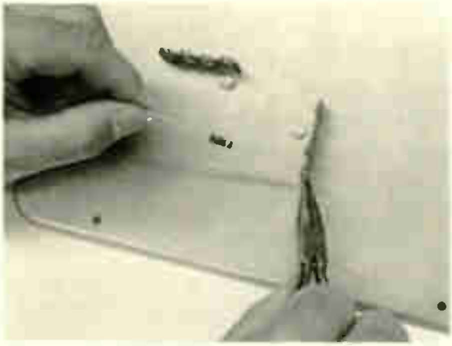


Fig. 20. Bending the lead.

The tube socket pins and lugs on the terminal strips that you will receive in your kits have been tinned. You should have no trouble in soldering to these terminals. However, before soldering to them, carefully examine them to be sure they are clean. If they are not, clean and tin them to avoid soldering difficulties later.

To solder a lead to a terminal strip or solder lug, place the lead through the opening in the terminal lug, as shown in Fig. 19. Bend the end of the lead slightly as in Fig. 20 so that the lead can be placed in contact with the metal part of the lug. Do not wrap the lead around the terminal strip lug unless you are told to do so. This type of connection is too difficult to remove. Later, when you begin wiring equipment that you will leave assembled permanently, you will wrap the leads around the various terminals in order to insure strong mechanical and electrical connections.

When you have the lead in place, hold your soldering iron against the terminal and against the lead, as shown in Fig. 21, to heat both of them to the solder-melting point. Unless you heat them both, you will not make a good connection.

Fig. 21. Soldering a connection.

After they are hot enough, touch the end of the solder to the terminal and lead, so that the solder will flow freely over the resistor lead and the terminal. Do not use too much solder. You want only enough to cover the resistor lead and hold it to the terminal. If you use too much, the solder will flow down the terminal strip and may short to the chassis. A properly soldered connection showing the correct amount of solder is shown in Fig. 22, and a connection with an excessive amount of solder is shown in Fig. 23.

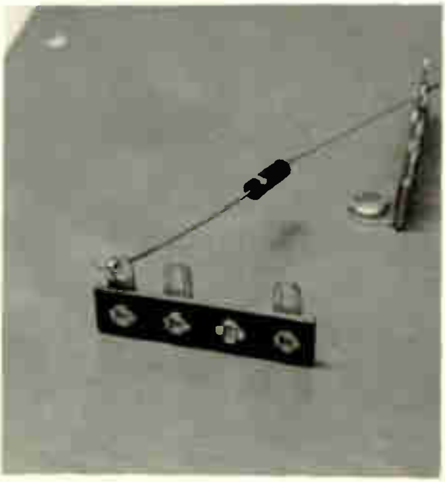


Fig. 22. Good solder connection.

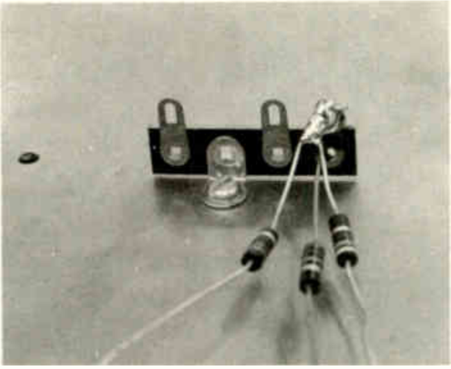


Fig. 23. Poor solder connection (too much solder).

When soldering a connection, do not be in a hurry to get the soldering iron off the connection. In most cases, it is better to hold the iron on the connection a little too long than it is not to hold the iron on long enough. When you are starting to solder, watch each connection carefully. Hold the iron on the connection long enough to allow the solder to flow freely. Solder should melt and flow in, around, and over all the leads you are attempting to solder to a terminal. The solder should also flow freely over the terminal. If you hold the iron on the terminal only long enough to melt the solder and have it start to flow, you will find that you have a rough-looking joint, and the chances are that if you apply pressure to the leads, they will pull loose. On the other hand, if you hold the iron on the joint long enough to allow the solder to melt completely and flow freely over the joint, you will have a smooth-looking connection that will be mechanically strong. This is extremely important - make sure that the solder flows freely over each connection you make.

Using Too Much Solder. Avoid using too much solder. It takes very little solder to make a good electrical connection. Usually, if you heat the terminal and lead sufficiently, you will find that a drop of solder will be all that is needed. Do not hold the soldering iron in place and simply melt more and more solder onto the joint. Once you have one drop of solder flowing around the joint, lift the solder off the terminal, but continue to heat the connection so that the solder that you have on the terminal flows around the leads and over the terminal. This may be all the solder you need. If not, add more solder and allow it to flow into the joint. If you use too much, the solder will flow between the pins and the chassis, and between the chassis and terminal strip lugs.

It is particularly important that you heat large wires thoroughly. You will often find in your radio, TV, or electronics work that you must solder transformer leads in place. Usually the leads from a transformer, particularly the leads from the filament winding on a TV replacement power transformer, will be of a fairly large size. In addition, they are made of copper, which is a good heat conductor. As a result, they can carry away a substantial amount of heat. You will have to be sure that you have the iron in good contact with the lead when making this type of connection.

Etched Circuit Wiring. Etched or "printed" circuit boards are used in many radio and TV receivers as well as in other types of electronic equipment. You can expect to have to wire and to repair circuit boards. Therefore, you should know how to do so.

Examine the etched circuit board included in your kit (NRI part EC24). This is fairly typical of the boards used in commercial equipment. The board consists of a sheet of phenolic, which is an insulating material, with a pattern of copper foil strips bonded to one side. Notice that the copper foil connects together holes in the circuit board. When parts are mounted on the board with their leads extending through these holes and soldered to the copper, the copper foil provides the electrical paths which connect the parts together to form circuitry.

We call them "etched" circuit boards because of the way the boards are made. Each board is cut from a large sheet of phenolic to which a sheet of copper foil has been bonded. The desired copper foil pattern is transferred to the board by a photographic process. The board is then placed in a highly corrosive solution which etches away the unwanted copper foil, leaving the desired foil pattern.

After the etching is completed, the board is cleaned and the holes are drilled or punched and the lettering and other markings are printed on the phenolic.

Parts are usually mounted on the phenolic side of the board and they are supported by their leads, as shown in Fig. 24. The leads are passed through the holes in the board and soldered to the foil. When you install a part, bend the lead outward slightly to hold the part until you can solder the leads. Place the tip of your iron in contact with the lead and the foil and apply solder. Allow a small amount of solder to melt and flow into and around the joint. After the solder cools, cut off the lead flush with the top of the soldered connection. Fig. 25 shows an etched circuit board with good soldered connections.

As you go through these experiments, pay particular attention to each soldered connection you make. Tin the part leads before attempting to solder them; heat each connection thoroughly; inspect each connection and wiggle the leads after it is soldered to make sure that it is a good solid connection. Try to develop sound soldering habits; they will save you a great deal of time and difficulty, not only in your experiments, but all through your electronics career.

Performing the Experiments. To get the most benefit from the experimental course, you should follow a logical, planned procedure in each experiment. When you start a new manual, always study first the introduction at the beginning of the book. Then perform the experiments one at a time, in the correct order, by observing the following procedures:

1. Read through the instructions and discussions for the entire experiment once very slowly, and study any parts that are not immediately clear to you. Do not touch a single tool or part until you make this preliminary study.

2. Lay out on your worktable the

Fig. 24. Phenolic side of an etched circuit board with the parts installed.

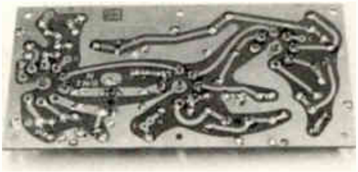


Fig. 25. Foil side of an etched circuit board, showing the parts installed.

parts and tools needed for the experiment to be performed.

3. Carry out the experiments one step at a time. Record your results whenever spaces are provided in the manual for this purpose. Additional observations and comments can be written in the margins of the pages for future reference.

4. Study the discussion at the end of the experiment very carefully, and analyze your results. After finishing an experiment, you should be able to tell in your own words exactly what you proved and how you did it.

5. Complete the Report Statement by writing the Statement Number on your Training Kit Report sheet in the space provided. Then enter the number of your choice for completing the Statement in the next column. Use the additional columns to the right for Statements that have more than one part.

6. When you have completed all ten experiments in the manual and have answered all of the statements, send in your Report Sheet for grading. Do not send in the manual.

EXPERIMENT 1

Purpose: To mount parts in a circuit; and to make soldered connections to these parts.

Introductory Discussion: Solder will hold parts together mechanically and fuse parts together so that they are, in effect, a single unit. A good soldered joint has little or no resistance and protects the surfaces of the parts from oxidation. Good soldered connections are a clue to the technician's ability. A man with an average knowledge of theory who can make good soldered connections will have less trouble than an expert on theory who cannot solder! In this experiment, you will mount parts and make several soldered connections. This experiment may seem simple, but do not pass over it quickly. The points that will be brought out are all very important.

Soldering ability is not hard to acquire and you should make this your first goal.

Experimental Procedure: Before you start the experiment, make sure your workbench is cleared so you will not lose any parts or have anything in your way. Gather your tools and the parts you will need in the experiment. At this time you should have a potentiometer, a solder lug and three terminal strips mounted on the chassis.

In the experiment, you will need the chassis with the parts mounted on it and the following parts:

3 1000-ohm resistors (RE30; brown-black-red-silver)
Rosin-core solder

Step 1: To prepare the parts to be soldered.

If you have the parts mounted on the chassis correctly, you are ready to wire the circuit by soldering resistors to various terminals. Plug in your soldering iron so that it can be heating.

Tin each lead of the three resistors until they are bright and shiny.

As you were instructed previously, you can use a knife or a small piece of sandpaper folded and held between the thumb and forefinger to clean the leads if they will not tin easily.

Test the iron by touching the end of the solder to the tinned tip of the iron. If the solder melts readily, the iron is ready for use.

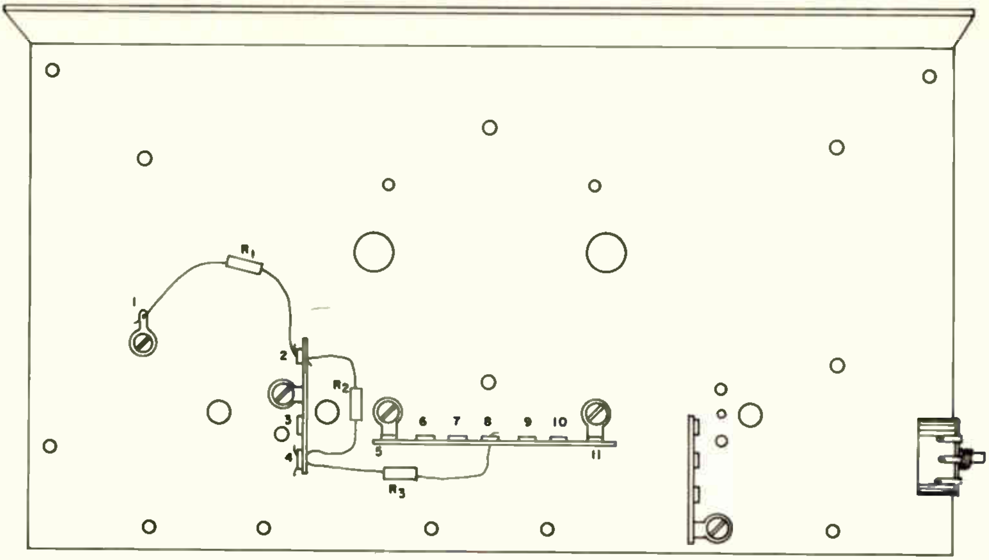


Fig. 1-1. Top view of the chassis, showing the resistors you will install in this experiment.

IMPORTANT: Do not cut the leads of any parts you received in this kit unless you are instructed to do so in the experiment. You will use most of the parts again in future experiments.

Fig. 1-1 shows you where you are to connect the resistors. The resistors are to be mounted so that the resistors and the leads are to be at least 1/2" above the chassis. As we mentioned earlier, we have given each terminal an identifying number. We will use these terminal numbers in this kit to indicate where the connections are to be made so as to simplify the instructions.

Connect the lead of one of the resistors to terminal 1, which is the solder lug mounted at hole B. Push the end of the lead through the hole in the solder lug and solder, as shown in Fig. 1-2.

Bring the tip of your soldering iron into contact with both the solder lug and the resistor lead, as in Fig. 1-2. Position the iron so that one flat surface of the tip is against the terminal. This permits maximum transfer of heat from the tip of the iron to the connection.

Touch the solder to the point where the terminal and the lead meet, and allow the solder to melt. Notice that the rosin flux flows out of the solder as the solder

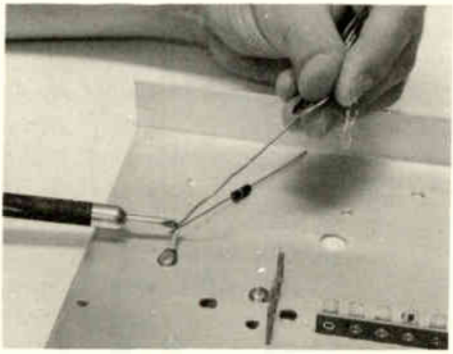


Fig. 1-2. Soldering the resistor lead to the terminal.

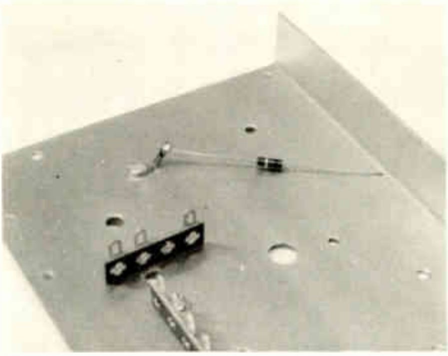


Fig. 1-3. Resistor R_1 soldered to terminal 1.

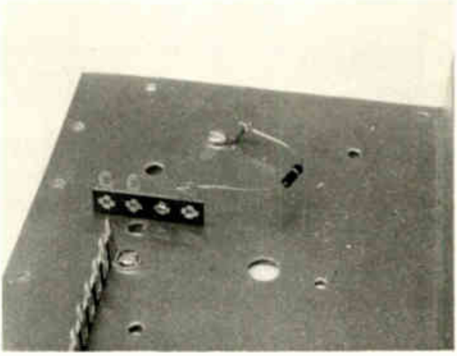


Fig. 1-4. Resistor R_1 in place on chassis.

melts. Remove the roll of solder and continue to heat the joint.

After the solder flows into the connection and coats the terminal and lead, remove the heat and allow the joint to cool and harden. Do not disturb the connection until the solder hardens.

If your solder joint is made correctly, the lead will be covered with solder where it touches the terminal and the solder should have a clean smooth appearance. Fig. 1-3 shows a good solder connection. The space between the resistor lead and the terminal is filled with solder and the solder also seals the connection.

It is a good idea to test each connection after it has cooled. To do this, grasp the resistor lead you have just soldered between the connection and the resistor body with your longnose pliers. Twist the lead gently and move it back and forth. If the lead does not move, you probably have a good soldered connection. If the lead breaks loose, or if the connection has a brown crust on it, re-melt the solder with your iron and let it cool again.

If you did make a poor solder connection, it may have been due to insufficient heat or to dirt on the lead or terminal. A poor joint can also result from your moving the lead before the joint has cooled.

Another problem which you might encounter is the "rosin" joint. This is a connection having a layer of rosin between the wire and the terminal. A rosin joint is indicated by a brown crusty appearance on the connection. You can correct a rosin joint by reheating the connection and allowing the rosin to boil out. As you heat the joint, you will see the vapor from the rosin rising from it.

With your longnose pliers, grasp the free lead of the resistor and slip it through the slot in terminal 2. Position the resistor as shown in Fig. 1-1. Twist the resistor slightly so the lead stays near the top of the slot in the terminal. Bend the end of the lead passing through the terminal so the lead touches the terminal, as shown in Fig. 1-4. Do not solder the connection at this time.

Step 2: To mount resistor R_2.

Now take another resistor and push the end of one lead about 1/8″ through the slot in terminal 2. Bend the end slightly to bring it into contact with the terminal. Solder both leads to terminal 2. Place the tip of your soldering iron in contact with both leads and the terminal, with a flat surface against the terminal. Touch your solder to the connection and allow a small amount of the solder to melt. Remove the roll of solder and allow the molten solder to flow into the connection. Remove the heat and let the joint cool.

Test each connection by twisting and trying to move each lead. If the joint does not break loose, and the solder looks smooth, you probably have an acceptable connection. If not, reheat the connection, remelt the solder and allow it to cool and test the connections again.

Bend the leads of resistor R_2 at a right angle about 1/2" from the body of the resistor and position the resistor as shown in Fig. 1-1. Connect the free lead of resistor R_2 to terminal 4. Do not solder it at this time, since another lead will be connected to the same terminal.

Step 3: To mount resistor R_3.

Connect another resistor, R_3, from terminal 4 to terminal 8. This time make the connection without detailed instructions. Bend the leads as required and position the resistor as shown in Fig. 1-1. Note that the body of the resistor should be about 1/2" to 3/4" from the 7-lug terminal strip. Solder and test both connections.

If you have done your work correctly, your chassis should look like Fig. 1-1. You should have a total of three resistors and four temporary soldered connections. We call them "temporary" because they can be disconnected easily, as you will see later. The solder provides both the mechanical strength and the electrical path between the leads and the terminals.

By contrast, a permanent connection does not rely on the solder for physical strength. Usually the wire is twisted or wrapped around the terminal for physical strength before the connection is soldered.

You will make only temporary soldered connections in the experiments in this manual. However, you will make permanent connections in later experiments. The instructions on how to make them will be given at that time.

Look over the connections you have made and examine them critically. Check to see if any solder has run down the terminal where it may make contact with the chassis and cause a short circuit. This condition is illustrated in Fig. 1-5. Also, look at each connection to see if solder has flowed to all parts of the joints. Look for big lumps of solder on the terminal. They indicate too little heat or too much solder.

Excess solder will do no harm, provided it does not short terminals together, short a terminal to the chassis, or contain excessive rosin. However, it looks messy and is a waste of solder. Too little heat means a poor connection; the cure is to hold the lead in position and reheat the joint.

Next you will unsolder the connections in order to learn the proper techniques for doing this.

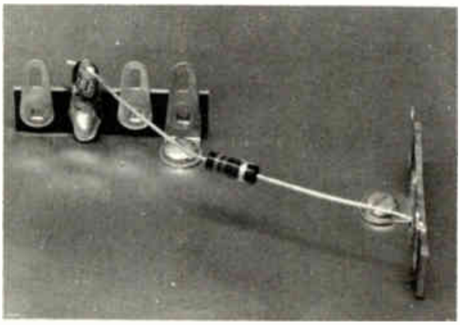


Fig. 1-5. A terminal shorted to the chassis by excessive solder.

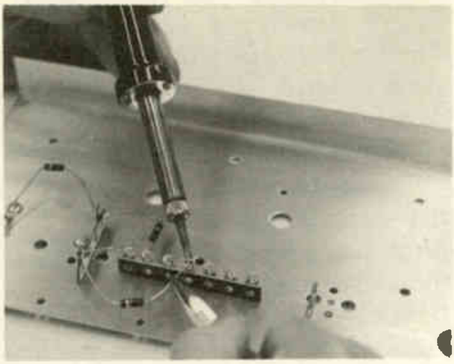


Fig. 1-6. Removing R_3 from terminal 8.

Step 4: To learn to unsolder connections.

Grasp the lead of R_3 connected to terminal 8 with your longnose pliers. See Fig. 1-6. Then touch the tip of your soldering iron to the connection. As soon as the solder melts, pull the lead out of the terminal. Wipe the tip of your iron with a cloth to remove the excess solder, and then touch the tip of the iron to the connections to terminal 4. Grasp the lead of resistor R_3 with your longnose pliers and, as soon as the solder melts, pull that lead free. Lay the resistor on your workbench. Grasp the lead of resistor R_2 connected to terminal 4. Apply heat to the terminal, and when the solder melts, pull the lead free. Wipe the excess solder from your iron with a cloth and then apply heat to the second lead of resistor R_2 which is connected to terminal 2. Remove the resistor and lay it on your work surface.

Use the procedure which we have outlined to unsolder the remaining connections and to remove resistor R_1.

Step 5: To clean parts so they will be ready for reuse.

Whenever you remove parts, clean the leads, lugs, and terminals so that you can use the parts again and connect other parts to the same lugs and terminals.

To practice this technique, first use your longnose pliers to straighten the resistor leads. Then, wipe any excess solder from the tip of your iron with a piece of cloth, and place the iron on the holder so that you can get to the tip easily. In one hand, hold a piece of cloth so that there are several thicknesses between your thumb and forefinger. With your longnose pliers in your other hand, grasp a resistor lead close to the body of the resistor. Hold the end of the lead against the tip of the iron until the solder on the lead melts, and quickly pull the hot lead through the cloth, as shown in Fig. 1-7. This will remove all excess solder and leave the lead surface clean and bright. Do this on all resistor leads that have been used in this experiment.

There are several methods of removing the solder from terminal and solder lugs. Probably the easiest and most efficient method to use on small pieces of elec-

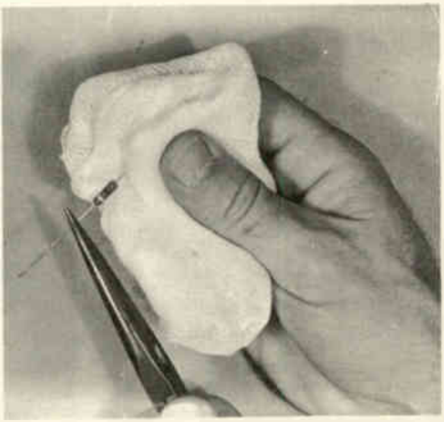


Fig. 1-7. Removing the excessive solder from a resistor lead.

tronic equipment, such as the experimental chassis you received in this kit, is to turn the chassis upside down so that the terminals are pointing downward. Apply the tip of the iron to the end of the terminal, and when the solder melts most of it will run onto the tinned surface of the iron. Wipe the excess solder from the tip and repeat the procedure on the other lugs on the terminal strip. If a thin film of solder remains in the terminal holes, wipe the excess solder from the tip of the iron and reheat the lug. Push a resistor lead through the hole to remove the solder.

In addition to removing the solder from the terminals, this method will remove any excess solder that may be on the terminal strip lugs near the chassis.

Removing excess solder from terminals, tube socket pins and other types of solder lugs in large pieces of electronic equipment that you cannot pick up and turn upside down requires a slightly different procedure. In this case, with the terminals pointing upward, wipe the excess solder from the tip of your iron and keep the cloth in one hand while you work. Touch the tip of the iron to the side of the lug; when the solder melts, some of it will run onto the tinned surface of the iron. Wipe off the solder and keep repeating the process until all surplus solder has been removed. If you have trouble getting the solder out of the hole in a lug, heat the lug and push a resistor lead through the hole. The solder that accumulates on the resistor lead can then be easily removed.

The same procedure should be used to remove solder from tube socket pins and terminal strip lugs.

Discussion: In this first experiment, you began acquiring one of the most important skills a technician must have -- the ability to make good soldered connections. You have had practice in mounting actual electronics parts and soldering them into place. You have been able to see how solder looks as it cools and hardens. You should not expect to be an expert at soldering at this time; it takes considerable practice. However, if you carefully follow the procedures discussed in this experiment, you should have no trouble making good soldered connections and you will soon become an expert with a soldering iron.

You have also had practice in the equally important task of unsoldering, and you have learned how to clean the parts so they will be ready for reuse. This is important because often the serviceman must disconnect one part in order to check another. When you disconnect a part or lead, you should carefully prepare it and the terminal from which you removed it before resoldering the lead back into position.

Instructions for Statement No. 1: In this statement, there are two sentences to be completed, each having several choices preceded by numbers. Only one of the choices in each group correctly completes a sentence in the statement. Read the first sentence, and put a circle around the number preceding the choice that completes it. Do the same for the second sentence.

Statement No. 1: In this experiment, I used

(1) temporary
(2) permanent

connections; and I found that as molten solder becomes hard, its appearance is

(1) a copper color.
(2) a shiny gray color.
(3) a dull black color.

SOLDERING TIPS

Always use a clean, hot, well-tinned iron.
Always heat the junction to be soldered enough to melt the solder.
Always use a rosin-core solder.
Always tin part leads to be soldered.
Always test all leads in each joint after solder cools.
Always keep iron on joint until the rosin has boiled out of the joint.
Never try to solder dirty or untinned leads or terminals.
Never melt solder on the iron tip and carry it to the junction.
Never use acid-core solder or pastes for radio and electronic work.
Never drip solder off iron on to joint.
Never let leads move while solder is setting.

Turn now to the enclosed Training Kit Report sheet. Fill in the top part with your name, address, student number and Kit number, 1T. Write the number 1 in the first box of the column with the heading, "Statement No." This statement is in two parts. Therefore, place the number of your choice for the first part in the second column and place the number of your choice for the second part of the statement in the third column. As an example, assume that the first statement was:

San Francisco is located in the

(1) East
(2) South
(3) West

And it is in the state of

(1) Nebraska.
(2) California.
(3) New York.

The correct answers are (3) for the first part and (2) for the second part. Therefore, you would place the Statement number in the first column, the number 3 as your answer for the first part is the second column, and the number 2 in the third column.

EXPERIMENT 2

Purpose: To learn how to wire and repair etched circuit boards.

Introductory Discussion: Etched circuit boards are often used where compactness, ease of wiring or freedom from circuit variations are important. The vast majority of radio and TV receivers use etched circuit boards. Thus, it is likely that when you repair a receiver you will have to make repairs on etched circuit boards.

Etched circuit boards are fragile. They can be damaged by rough handling or poor workmanship. The phenolic will crack or break when subjected to excessive pressure. This results in breaks in the copper foil strips and produces open circuits.

The copper foil is glued to the circuit board. When overheated, the glue will weaken and the copper foil strips will pull loose from the board. However, the board will withstand a surprisingly large amount of heat before either the phenolic or the foil becomes damaged.

In performing this experiment, you will develop skill in working on etched circuit boards. This will prepare you for work on your future experimental kits and for practical work as a technician.

Experimental Procedure: In this experiment, in addition to your chassis, soldering iron and solder, you will need the following:

1	Etched circuit board (EC24)
2	22,000-ohm resistors (RE33; red-red-orange-silver)
1	7-pin tube socket (SO76)
	Red hookup wire
	Solder

Plug in your soldering iron so that it can be heating. Inspect the tip. If the tip is not clean, wipe it with a cloth and apply a thin coating of solder. If you wipe the tip frequently, it will last longer. Also, you will seldom have to file and retin the tip.

In this experiment, you will practice soldering to the etched circuit board and you will make repairs on the copper foil. The foil near holes A through H is for practice only. Do not be concerned if you damage it in performing this experiment. However, the remainder of the board will be used in later experiments. Therefore, you should exercise reasonable care in working on the board.

Step 1: To wire a circuit on the etched circuit board.

In order to become proficient at working on circuit boards, you will have to develop a feel for soldering to the copper foil. Before mounting any parts, you will determine how much heat the foil can withstand.

Place your etched board on your worktable with the foil side up. Touch the tip of your soldering iron to the foil near hole B. Hold the soldering iron nearly straight up with the tip at the edge of the hole, as shown in Fig. 2-1. Touch the end of your solder to a point where the tip touches the foil. Allow about 1/4" of solder to melt and flow onto the foil. When the solder spreads out smoothly on the foil, remove the heat and allow the foil to cool. Do not be concerned if the hole is covered with solder.

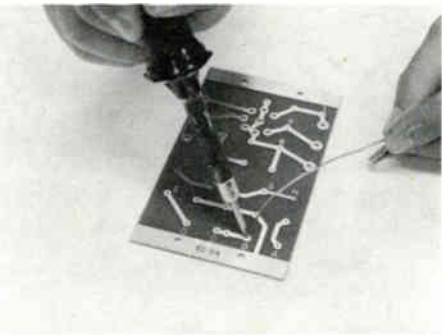


Fig. 2-1. Applying heat and solder to the foil.

In a similar manner, apply heat to the foil surrounding hole A. Touch your solder to the iron and the foil and melt about 1/4" of the solder. Continue to heat the foil until the foil begins to loosen. This may take up to 15 seconds, depending upon the wattage rating of your iron and the condition of the tip. Remove the heat from the foil.

Notice that the phenolic around the overheated foil is charred slightly. Use a knife or your longnose pliers to peel the damaged foil off the board.

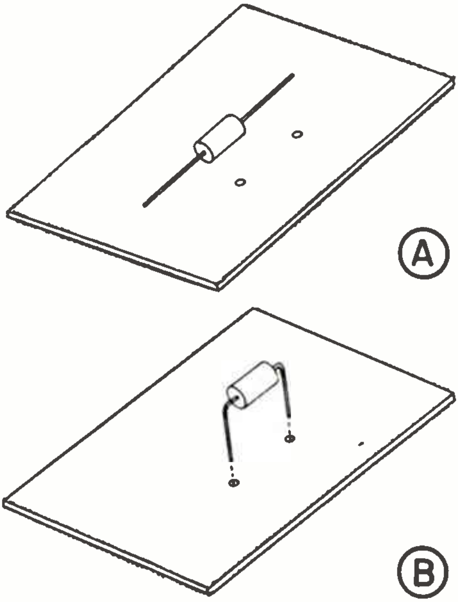


Fig. 2-2. (A) Measuring the resistor against the mounting holes; (B) resistor leads bent to correct spacing.

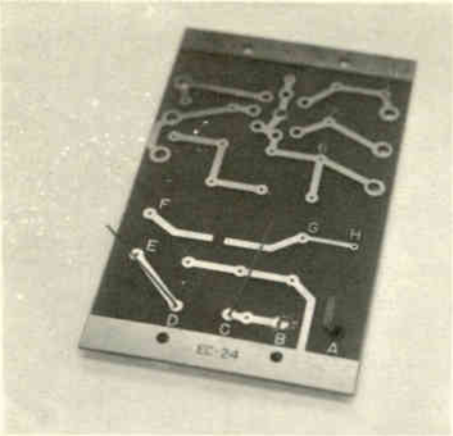


Fig. 2-3. Leads are bent outward to hold the resistor in place.

The brief experience which you have gained will give you some idea of how long it takes to make a connection and how long it takes to damage the circuit board. Next, you will mount and solder parts to the circuit board.

Install one of the 22,000-ohm resistors (red-red-orange-silver) on the phenolic side of the circuit board at holes C and D. Use the following procedure: First, "measure" the resistor against the spacing between the holes, as shown in Fig. 2-2A. In this case, the spacing between the holes is about 1/4" greater than the length of the body of the resistor, so bend both leads at right angles about 1/8" from the body of the resistor. Fig. 2-2B shows the leads ready for insertion in the holes.

Next, slip the leads through holes C and D and push the resistor down against the board. Bend the leads outward slightly, as shown in Fig. 2-3, to hold the resistor in place.

Turn the foil side of the circuit board up to solder the connections. Position the soldering iron so that the tip is in contact with both the foil and the lead. Touch the end of your solder to the point where the tip, lead and foil meet and allow about 1/4" of the solder to melt. Continue to heat the connection until the solder flows smoothly and completely surrounds the lead. Then, remove the iron and allow the connection to cool.

Finally, use your diagonal cutters to cut off the lead flush with the top of the solder connection.

Use the procedure outlined here to solder the other resistor lead to the foil.

Fig. 2-4 shows typical poorly soldered

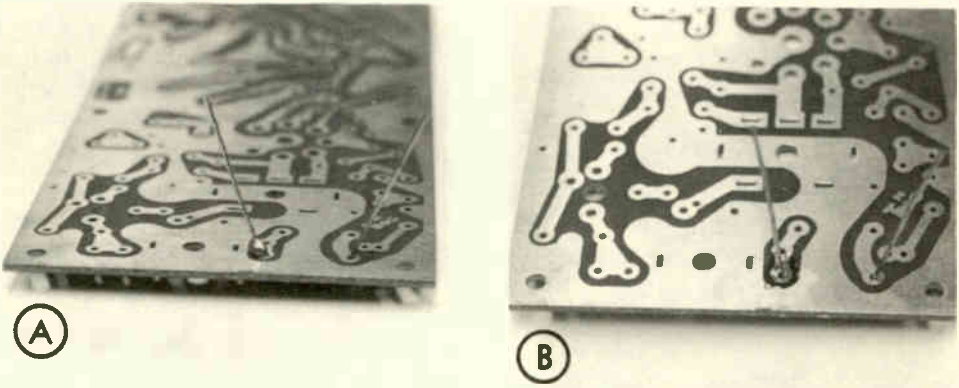


Fig. 2-4. Typical examples of poorly soldered connections.

connections. At A, too little heat was used; the solder adheres to the lead, but not to the foil. This connection could be improved by simply applying more heat. In Fig. 2-4B, too little solder was used, resulting in a minimum of strength and reliability. To improve this connection, you would apply both heat and solder.

Step 2: To demonstrate methods for removing components from etched circuit boards.

Wedge the blade of your small screwdriver between the board and the body of the resistor near hole C. (If the resistor is flat against the board, slip the screwdriver blade under the lead at hole C.) Heat the solder at hole C and lift the resistor enough to pull the lead from the hole.

Stand the circuit board on edge on your worktable. On the phenolic side of the board, grasp the lead of the resistor connected at hole D. With your forefinger and thumb pressing against the board, apply a lifting pressure to the resistor lead. Heat the connection at hole D on the foil side and when the solder melts, pull the resistor from the board and discard it.

Now you should clean the holes so that a new resistor can be installed. Heat the solder at one of the holes. While the solder is molten, insert a toothpick into the hole from the foil side of the board. Remove the soldering iron and let the foil and solder cool. When you remove the toothpick, the hole will be left clear.

Step 3: To demonstrate techniques for repairing etched circuit boards.

Cut through the foil between holes D and E to simulate a crack in the foil. You can use your pocket knife. Fig. 2-5 shows how to make a clean cut safely.

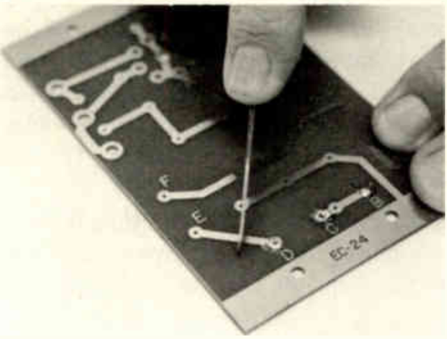


Fig. 2-5. Cutting the foil to simulate a crack in the board.

Heat the foil near the cut and melt a small amount of solder onto the foil. Use the tip of your iron to "run" the solder across the crack. The solder should adhere to the foil on both sides and bridge the narrow gap. If necessary, apply a little more solder to make a reliable repair.

A wider break, such as the one between holes F and G, requires a slightly different repair. You solder a short piece of bare wire across the break in the foil.

Remove about 2" of insulation from a length of red hookup wire. There are several ways of removing the insulation. You can peel the insulation off with a knife, or you can cut the insulation with your diagonal cutters, knife or wire strippers and simply pull off the unwanted piece. Another technique is to crush the insulation with pliers and then peel off the pieces. When stripping the insulation off wire, it is important to avoid nicking or cutting the wire because this will weaken the wire and make it break easily.

As you did previously for the narrow break, heat the foil on both sides of the break and tin the foil with solder. Lay the bare wire across the break in the foil and solder the wire to the foil. Run solder along the wire and foil for about 1/2″ on each side of the break. Using your diagonal cutters, cut off the wire beyond the solder. This should leave about 1″ of wire bridging the break in the foil.

Step 4: To install parts on the foil side of the circuit board.

Bend the leads of a 22,000-ohm resistor (red-red-orange-silver) at right angles close to the body of the resistor, and insert the leads through holes C and D from the foil side of the board. Position the resistor about 1/16″ to 1/8″ from the board. This will leave room for soldering the connections. Bend the leads outward slightly to hold the resistor in place.

Solder one lead of the resistor to the foil. Apply heat to both the foil and the lead and apply solder. Allow the solder to flow freely over the connection. Remove the heat and let the joint cool. In a similar manner, solder the other resistor lead to the foil. You will use this resistor in later experiments, so do not cut off the leads! (Normally, after installing a part from the foil side as you have just done, you would clip off the excess lead length on the other side of the board.)

Locate the 7-pin tube socket. The socket has 7 pin connections and a center locating pin. You will install the tube socket on the *foil* side of the circuit board instead of from the phenolic side. Align the pins over the holes on the circuit board. Notice that there is an open space between the pins. Install the socket on the board by pushing firmly. When the socket is properly installed, the pins project about 1/16″ on the phenolic side of the board.

With the socket in position, you are ready to solder. Since the tube socket pins on the phenolic side of the board will become quite hot as you solder them to the board, it would be a good idea to lay the board on a newspaper to protect your worktable. Hold the soldering iron so the tip is at the junction of the foil and a pin of the tube socket.

The flat surface of the soldering iron tip should be turned toward the pin. Apply solder to the foil and to the pin. Melt about 1/4″ of solder and let it flow around the pin. Solder should adhere to one half or more of the perimeter of the pin and to the foil. Remove the heat and let the solder cool. In the same manner, solder the six remaining pins of the tube socket. Do not try to solder the center locating pin. Fig. 2-6 shows the socket soldered in place.

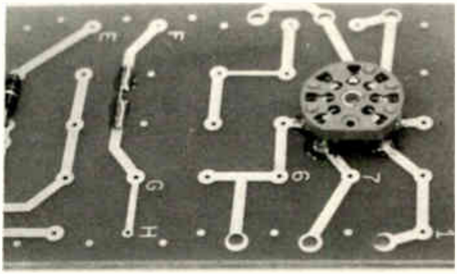


Fig. 2-6. Tube socket mounted on the etched circuit board.

Discussion: In this experiment, you have experienced working on a typical etched circuit board. You learned that you can solder to the circuit board with a moderate amount of heat. If the iron is clean and tinned, a connection can be soldered in a matter of seconds; it takes a considerable length of time to overheat and damage the circuit board.

In Step 2, you learned how to install components on the circuit board. First, you determined the lead spacing and bent the leads so you could insert the leads in the holes; then you pushed the part down against the circuit board and bent the lead to hold the part in place. Then you soldered the connection, allowed it to cool, and cut off the excess lead length, close to the soldered connection. In a good solder connection, the solder adheres to both the lead and to the foil and the solder has a smooth appearance.

You also learned how to remove parts from the etched circuit board. This is important because frequently you will have to disconnect a part to make tests and when you determine which part is bad, you will have to replace it. Before replacing a lead, clean the hole in the board. Otherwise, you may break the foil loose when you try to insert the lead.

In Step 4, you learned how to install parts on the foil side of the board. This is useful because you will sometimes find it easier to replace a part on the foil side of the board. Also, interconnecting jumper wires are sometimes connected on the foil side of the board in some pieces of equipment.

The circuit board with the tube socket attached will be used in later experiments.

Instructions for Statement No. 2: In order to answer the Report Statement for this experiment, you will have to make a few connections on your etched circuit board and trace the connections. You will need your red hookup wire.

Cut a 2" length of hookup wire and remove about 1/4" of insulation from each end. Push one end through hole E from the phenolic side of your circuit board. The holes are identified on the foil side of the board. Bend the wire and push the other end through hole F from the same side of the board. Solder both connections.

Cut a 3" length of hookup wire and remove about 1/4" insulation from each end. Push one end of the wire through hole G and push the other end through the hole identified by the number 7 from the phenolic side of the board. Solder both connections.

Trace the connections on the circuit board and answer the Report Statement. After you have completed the Report Statement, unsolder and remove the resistor and the pieces of hookup wire. Clean the holes which you used on your circuit board and clean and straighten the resistor leads.

Statement No. 2: When I traced the wiring, I found that the resistor

(1) was
(2) was not

electrically connected to the tube socket.

Using Schematic Diagrams

To service any type of electronic equipment, the technician must know how the parts are connected in the circuit.

The electrical connections in a circuit can be shown by means of a schematic diagram. In a schematic diagram, symbols are used to indicate the various parts, and the connections between the parts are shown by lines.

You have already seen many of the symbols used in schematic diagrams in your lesson texts. You have also seen some simple schematic diagrams. It is extremely important for you to become familiar with the various symbols used, and also to learn how to read schematic diagrams. You will have to use this type of diagram throughout your career, because manufacturers of electronic equipment seldom supply pictorial wiring diagrams. Even if you have a pictorial diagram, it is far easier to work from a schematic once you learn how to use it.

In your experiments, you will start first with simple schematics, and gradually work up to more complex ones. In time, you will be as much at ease reading a complex schematic diagram as you are reading your evening newspaper. You will soon learn the value of this type of diagram and see how much easier it is to use than the pictorial type.

SYMBOLS USED

Before you can read schematic diagrams, you must be able to recognize the symbols used in them. Fig. 26 shows the symbols commonly used to represent resistors, capacitors, and ground connections. Study these symbols so that you will be sure to recognize them the next time you see them. You will use them in these experiments.

Fig. 26. Symbols often used in schematics.

Connections and Crossovers. Often in a schematic diagram, one lead crosses over another. In some cases, there will be a connection between the two leads; in other cases, there will be no connection. There are three different systems in use to indicate whether or not there is a connection; the one that is used in any particular diagram depends on the preferences of the person making the diagram. You might think that this would be confusing, but it is usually very simple to see which system has been used.

Fig. 27 shows the three systems. Notice that in System 1 when there is a dot used on some crossovers and no dot used on the others, the dot indicates a connection, and the crossover without the dot indicates that there is no connection.

In System 2, a straight crossover is used to show a connection, and a loop is used to show no connection. You can easily tell when this system has been used. If you notice some crossovers with the loop, and some without the loop, you know that the straight crossovers represent connections, and the crossovers with the loop indicate no connection. Similarly, if you see some crossovers with dots and others without, you will know that System 1 has been used.

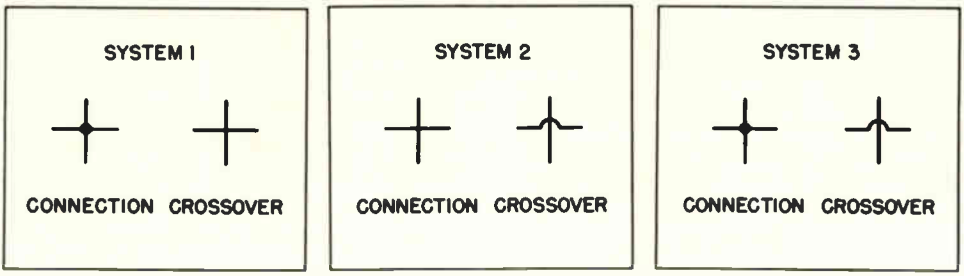


Fig. 27. Three systems used on schematics to show connections and crossovers on wires.

System 3 is a combination of the first two. We will use this system in the drawings in the experiments. The crossover with a dot indicates a connection. The crossover with a loop indicates no connection. Study these three systems - become familiar with them now, and you will have no trouble later.

Tubes. The various symbols used to represent the elements in a tube are shown in Fig. 28. The symbol for the heater is shown at A, the symbol for the cathode at B, for the grid at C, for the plate at D, and for the whole tube at E. This tube is called a triode - it has three elements plus a heater. Notice the little numbers beside each of the elements. These tell you which pin each element is connected to inside the tube. The tube we have shown is a 6C4. In this particular tube, the plate is connected to pins 5 and 1; the grid to pin 6, the cathode to pin 7, and the heater to pins 3 and 4. Nothing is connected to pin 2.

Diodes. The symbol for a semiconductor diode is shown in Fig. 29. The two elements of a diode are the cathode and the anode. The "arrow" in the symbol points toward the cathode terminal.

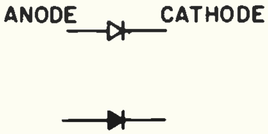


Fig. 29. Schematic symbols for a semiconductor diode.

Transistors. There are several types of transistors in wide usage. The symbols for two types are shown in Fig. 30. At A and B, we have bipolar transistors. As you can see, the only difference between the NPN and PNP symbols is the direction of the arrow. The e, b, and c labels identify the emitter, base and collector of both transistors.

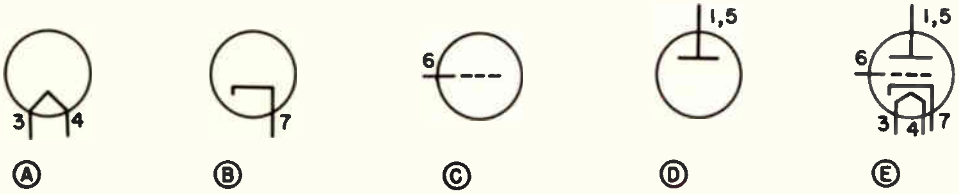


Fig. 28. Symbols used to represent the elements in a tube. Shown is tube type 6C4.

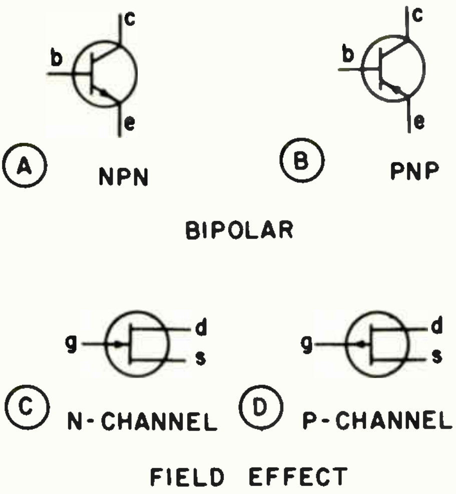


Fig. 30. Schematic symbols for transistors.

The symbols for junction field-effect transistors (FET's) are shown in Figs. 30C and 30D. You can see that the direction of the arrow is toward the junction for the N-channel and away from the junction for the P-channel FET's. In both cases, the s, g and d represent the source, gate and drain terminals. You will learn other transistor symbols later in your course.

Meters. Fig. 31 shows symbols used to represent meters on schematic diagrams. In the symbols in Fig. 31A, the letters inside the circle indicate the type of meter: V for voltmeter, μa for microammeter, ma for milliammeter, and ohm for ohmmeter. Fig. 31B shows semi-pictorial symbols that are sometimes used.

READING A SCHEMATIC

When working with schematic diagrams, you must remember that the schematic diagram shows the electrical connections, not the actual physical connections. An example of this can be seen in Fig. 32A. The schematic diagram shows the capacitor C_1 connected on the left to resistor R_1. From the junction of these two components there is a line going to the plate of the tube V_1.

In your work you will be interested only in the electrical connections. It will be unimportant to know whether the capacitor and resistor are first connected together and a lead run from the junction of the two to the tube socket, or whether the two are connected directly to the tube socket. Electrically both connections are the same.

The other side of capacitor C_1 is connected to the grid of the tube marked V_2. The schematic diagram shows C_1 connected to R_2 and then a line going from the junction over to the grid. The pictorial wiring diagram shows that both the capacitor and the resistor are connected directly to the grid terminal on the socket.

Notice on the schematic diagram that the lower end of resistor R_2 is connected to ground. In the wiring diagram, we see

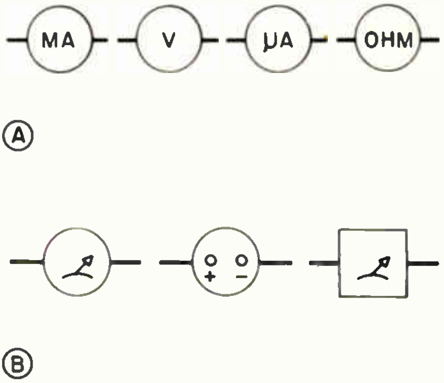


Fig. 31. Symbols used on schematics to represent meters.

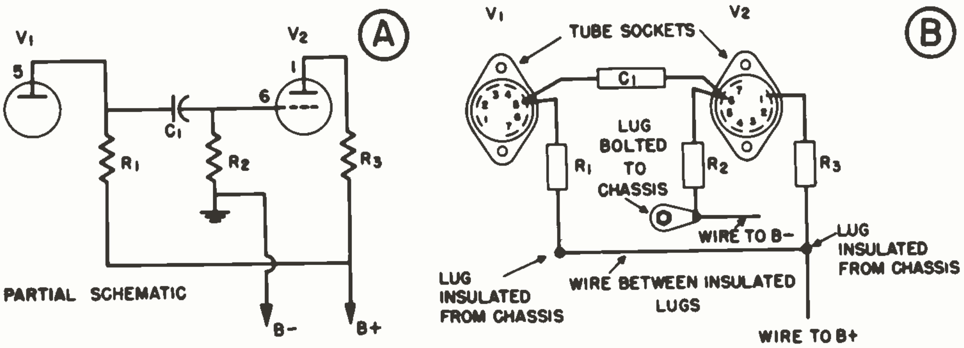


Fig. 32. (A) A schematic diagram; (B), actual wiring diagram of the same circuit.

that R_2 connects to a lug that is bolted to the chassis. Any number of ground connections can be made in this way to the chassis. When this is done, the chassis is used as part of the circuit; the chassis connects directly to B-. In some equipment the chassis is not used as part of the circuit. You will see later how to tell from a schematic diagram whether or not the chassis is part of the circuit. This information will be given to you on the schematic diagram.

Study Fig. 32 carefully. Find an electrical circuit on the schematic diagram, and then trace out the circuit on the pictorial wiring diagram. This will be valuable practical experience for you and will help you to become familiar with schematic diagrams.

EXPERIMENT 3

Purpose: To obtain practical experience in wiring from a schematic diagram.

Introductory Discussion: Fig. 3-1 is a pictorial diagram showing the actual physical location of the parts in the circuit you will wire in this experiment.

Fig. 3-2 shows the same circuit in schematic form. The circuit is that of a simple power supply. If an ac voltage were connected between terminals 1 and 2, a variable positive dc voltage would be available between terminals 17 and 15.

In a simple circuit of this type a pictorial diagram may seem easier to follow than a schematic diagram. However, a glance under the chassis of any electronic device will show how complex the pictorial diagram would become. In fact, it would be practically impossible to show how the parts are connected with a photograph or pictorial drawing. On the other hand, it is easy to show the connections with a schematic diagram.

Experimental Procedure: In this experiment, in addition to the chassis with the terminal strips and potentiometer mounted on it, you will need:

3 1000-ohm resistors (RE30; brown-black-red-silver)
1 Silicon diode (SR12)
Hookup wire
Solder

As you can see in Fig. 3-1, the diode appears similar to a resistor and is somewhat smaller. The diode is a semiconductor device which passes current in one direction only. Current can pass from cathode to anode but not from anode to

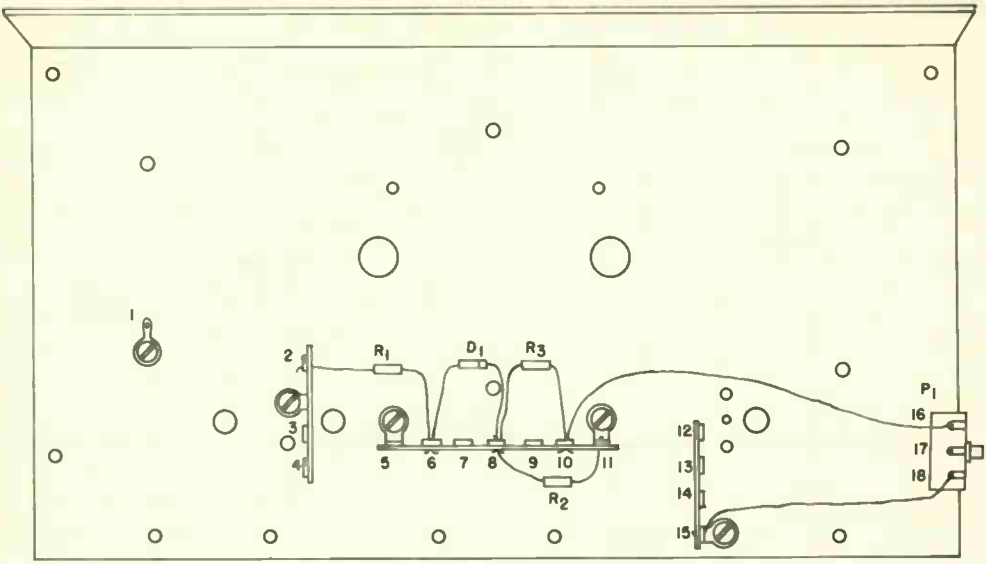


Fig. 3-1. Pictorial diagram of the circuit used in Step 1.

cathode. Thus, the diode is capable of rectifying an ac voltage.

The cathode and anode terminals of a diode are identified in one of several ways. You will usually find colored bands or a plus sign near one end of the diode, or one end of the diode may be tapered. The band, taper or other markings indicate the cathode lead of the diode as shown in Fig. 3-3.

Step 1: To determine what connections are to be made.

First, carefully study Fig. 3-2. Resistor R_1 is connected between terminal 2, which is the "input" terminal, or the terminal to which the ac voltage would be applied, and the diode D_1. The cathode lead of diode D_1 is connected to resistors R_2 and R_3. One lead of R_2 is grounded.

Resistor R_3 is connected between the junction of diode D_1 and resistor R_2 and the potentiometer, P_1. Potentiometer P_1 is connected between R_3 and ground.

Notice the ground symbols on the diagram. The metal chassis forms the common connection between the ground points.

Where possible, leads of the parts which are wired together are connected to a common terminal. For example, the cathode lead of D_1, one lead of R_2 and one lead of R_3 can all be soldered to the same terminal.

When instructed to use hookup wire, cut a length of your red wire and remove about 1/4″ of insulation from each end before making the connection. See that the insulation is about 1/16″ back from the actual solder connection. Never try to solder to the insulation.

When we instruct you to use a short length of bare wire, use your wire strippers, diagonal cutters or longnose pliers to remove the insulation from a short length of hookup wire.

In the next step, you will perform the actual wiring.

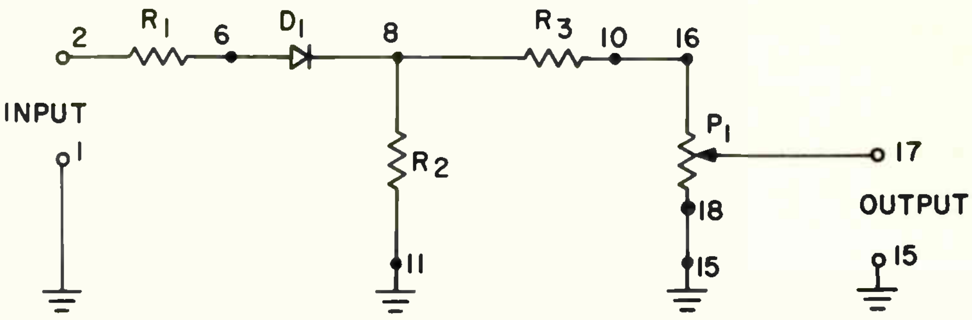


Fig. 3-2. Circuit used in Experiment 3.

Step 2: To wire the circuits from the schematic diagram.

In this step, you will mount the parts and connect wires between them to form the circuit shown in the schematic diagram in Fig. 3-2.

Connect resistor R_1 to terminals 2 and 6 as shown in Fig. 3-2. You can choose any of the three resistors since they are all the same value. Bend the leads so that the ends are spaced properly to slip through the slots in terminals 2 and 6. Slip the leads through the terminals and solder terminal 2.

Connect the diode to terminals 6 and 8 with the proper polarity. The cathode and anode leads are identified in Fig. 3-3. The cathode lead of each diode is on the right. Connect the cathode lead to terminal 8 and connect the anode lead to terminal 6. Solder terminal 6.

On the schematic diagram, notice that the cathode lead of the diode and one lead of resistor R_2 are connected together. Also, R_2 is connected from the junction with the diode lead to ground. Therefore, connect R_2 between terminals 8 and 11 as shown in Fig. 3-1. Solder terminal 11.

Next connect resistor R_3. On the schematic, this resistor is connected between the junction of diode D_1 and resistor R_2 and terminal 16 of the potentiometer. For convenience, we connect the resistor between terminals 8 and 10 and use hookup wire to complete the connection.

Install the resistor and solder terminal 8. Connect a length of hookup wire from

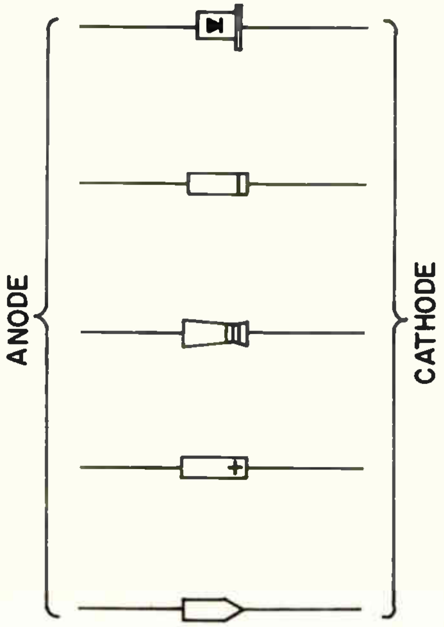


Fig. 3-3. Methods used to identify the leads of semiconductor diodes.

terminal 10 to terminal 16 and solder both connections.

The potentiometer is connected between resistor R_3 and ground. Thus, we must ground terminal 18. Again, we choose a convenient grounded terminal, which is terminal 15. Connect a length of hookup wire from terminal 18 to terminal 15 to complete the wiring. The center terminal of the potentiometer, terminal 17, is the "output" terminal.

This completes your wiring. You should have made all of the connections shown in Fig. 3-1. To make certain, check your wiring as follows:

1. There should be a resistor, R_1, between terminals 2 and 6.
2. Diode D_1 should be connected between terminals 6 and 8, with the cathode lead to terminal 8.
3. Resistor R_2 should be connected between terminals 8 and 11.
4. Resistor R_3 should be connected between terminals 8 and 10.
5. There should be hookup wire from terminal 10 to terminal 16 on the potentiometer.
6. There should be a length of hookup wire from terminal 18 on the potentiometer to terminal 15.

You should make a habit of checking your connections in this way each time you finish wiring a circuit. By checking your work, you may find and correct errors that could be serious or difficult to find later. When you check your work, pay particular attention to the soldered connections. Be sure that all connections are soldered properly. If not, resolder them.

When you are satisfied with your work, unsolder all of the connections and remove the parts. Straighten the resistor and diode leads and remove the excess solder from all terminals. Use the techniques you learned in Experiment 1.

Remove the 1000-ohm potentiometer from the mounting bracket and carefully clean the terminals. Remove the potentiometer mounting bracket and put it with the potentiometer. You will use these in a later Training Kit.

Discussion: In this experiment, we have taken you step-by-step through the wiring of a circuit from a schematic diagram. You have checked your work by comparing the actual parts layout with a list of the connections and with a pictorial diagram. This layout is not the only one that could be made from the schematic of Fig. 3-1. The same electrical circuit could have been made with the leads routed along different paths.

You should practice drawing schematic diagrams because such practice will help you to become more familiar with schematic symbols and will aid you later in tracing circuits. You need not start with elaborate diagrams; simple circuits like those shown in this experiment will be satisfactory.

The schematic diagram shows electrical connections only. Therefore, additional information is needed in order to wire more complex circuits. Experienced technicians usually sketch a layout before wiring. However, once a circuit is wired, it is easy to trace the circuit by following the schematic diagram.

Instructions for Statement No. 3: This statement is a test of your ability to relate a physical parts layout to a schematic diagram of that layout. Fig. 3-4 shows a circuit wired on your experimental chassis using resistors, a diode and a potentiometer.

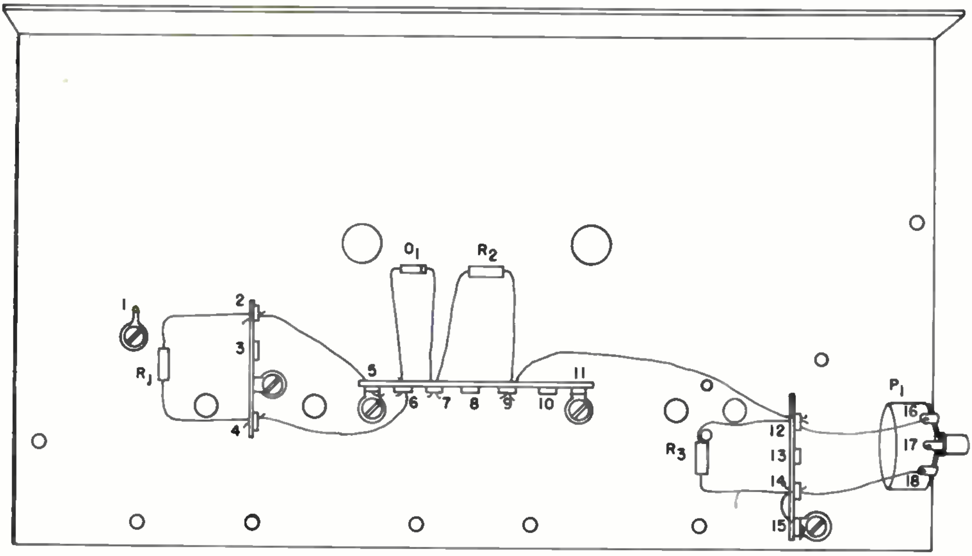


Fig. 3-4. Pictorial diagram of the circuit shown in Statement 3.

Study this circuit carefully and compare the arrangement with the four schematics in Fig. 3-5. When you are certain you have the schematic which corresponds to the circuit of Fig. 3-4, complete the statement here and on your Report Sheet.

Statement No. 3: The schematic diagram of the circuit in Fig. 3-4 is Fig. 3-5:

[✓ *(1) A*]
(2) B
(3) C
(4) D

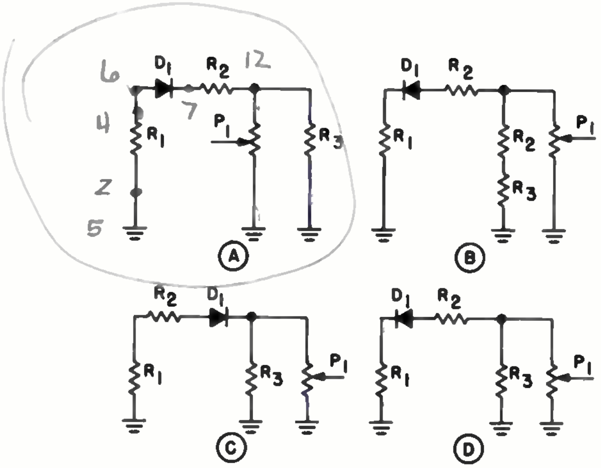


Fig. 3-5. Schematics for use with Statement No. 3.

IDENTIFYING RESISTORS

As you go ahead with your experiments, and when you work on your own, you will need to be able to identify the value of resistors.

Although the value is stamped on some resistors, on most 1/2-watt, 1-watt, and 2-watt resistors the value is indicated by means of colored bands on the resistor. You should learn to read this color code so that you can identify resistors quickly.

The colored bands on the resistor usually are nearer to one end than the other. Thus, to read the color code, turn the resistor so that the colored bands are toward the left end of the resistor as shown in Fig. 33.

Each color represents a number. These are given in Fig. 33. The first band, labeled A, gives the first figure in the value; the second band, labeled B, gives the second figure in the value; the third band, labeled C, gives the number of zeros after the second figure in the value, and the fourth band gives the tolerance of the resistor (silver for ±10% tolerance, gold for ±5% tolerance). If the tolerance is ±10%, it means that the actual value of the resistor may be as much as 10% higher or lower than the value indicated. If it is ±5%, the actual value may be up to 5% higher or lower than the value indicated.

COLOR	FIGURE
BLACK	0
BROWN	1
RED	2
ORANGE	3
YELLOW	4
GREEN	5
BLUE	6
VIOLET	7
GRAY	8
WHITE	9

COLOR A GIVES FIRST FIGURE OF RESISTOR VALUE.

COLOR B GIVES SECOND FIGURE OF RESISTOR VALUE.

COLOR C GIVES THE NUMBER OF CIPHERS FOLLOWING THE FIRST TWO FIGURES.

COLOR D GIVES THE TOLERANCE

GOLD BAND INDICATES ±5%
SILVER BAND INDICATES ±10%
NO BAND INDICATES ±20%

Fig. 33. Standard resistor color code.

Some resistors may have a fifth color band. This band will follow the tolerance band (to the right) and is used to indicate a military reliability level. The fifth band will be Brown, Red, Orange or Yellow which indicate increasing percent of reliability. In your work you can simply ignore the fifth band.

To find the value, you need to look only at the first three bands. For example, suppose you have a resistor color-coded red, red, and black. Referring to the chart, you see that red represents 2. Therefore, the first two figures in the value are both 2. As we have said, the third band indicates the number of zeros in the value. Since black represents 0, when the third band is black, there are no zeros in the value. So the value of the resistor is 22 ohms.

If the resistor had been color-coded red, red, and brown, the first two figures would again be 2. Brown represents 1, so there would be one zero, and the value would be 220 ohms. Red, red, and red would indicate a value of 2200 ohms (often written 2.2K ohms, where the K stands for 1000); red-red-orange, a value of 22,000 ohms (often written 22K-ohms); red-red-yellow, a value of 220,000 ohms (or 220K ohms or .22 meg; a megohm is 1,000,000 ohms); red-red-green, a value of 2,200,000 ohms (or 2.2 megohms); and red-red-blue, a value of 22,000,000 ohms (or 22 megohms).

Look over the resistors you have received, and practice reading the color codes on them. You can check the values by referring to the parts list given in Fig. 1. In the next experiment you will have some practice in picking out resistors of different values.

EXPERIMENT 4

Purpose: To construct a circuit using only a schematic diagram for guidance.

Introductory Discussion: If you read construction articles in any of the radio-TV-electronics magazines, you will see that step-by-step wiring instructions are rarely given; you work from a schematic diagram. Thus, if you wanted to build some of this equipment, you would have to work out the placement of the parts and other details for yourself.

We want you to become so familiar with schematic diagrams that you can look at one and picture the arrangement of the parts. That is not hard if you start with simple circuits like those you have built so far, and gradually work up to more complex circuits. The manufacturer's servicing information on any equipment usually has a complete schematic diagram and the parts values. If you are servicing the equipment, you will have to find the defective part, determine its value, and make the replacement.

Usually connections between parts are shown by a line that follows the shortest path between the two parts. However, this is not always true. The only sure way to find the part is to trace the circuit. Often it is more convenient to run a lead over a somewhat longer path to avoid crowding a section of the diagram. An example of this is given in Fig. 4-1. We could have drawn a horizontal line directly from pin 4 of V_1 to pin 3 of V_2 to show that they are connected. However, the line would have had to cross a number of other lines, thus crowding the diagram, and perhaps causing some confusion. Drawing the line as in Fig. 4-1 avoids confusion.

Tracing circuits on a schematic diagram is in many ways like tracing a road between your home and another city on a

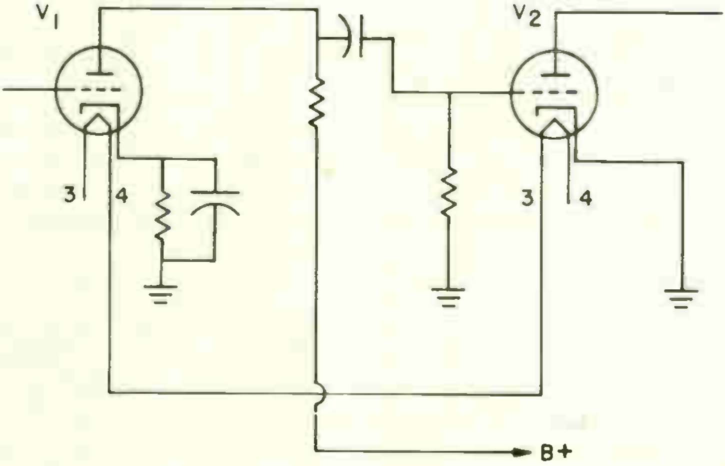


Fig. 4-1. Typical schematic diagram showing a two-stage tube circuit.

road map. You will seldom find a road that goes in a straight line from one place to another. Instead, the road will turn time and time again; you may have to go a certain distance on one road and then turn onto another. So it is in tracing the circuit on a schematic diagram. You start at one point in the circuit and trace toward another point. You may find a direct circuit between the two points, but more often you will find the circuits are connected by something other than a direct connection. In addition, you may find that to get from one point to the other you have to trace the circuit to some intermediate point, and then from that point on through an additional circuit to the point that you are interested in reaching.

Frequently in service work you will have to trace out the actual wiring in a receiver and compare the wiring with a schematic diagram. We cannot stress too strongly how important it is for you to learn to use this type of diagram. This is why we will concentrate on learning how to use diagrams.

When you work from a schematic diagram in the experiments, there may be several ways in which the various leads can be run. In general, try to use the shortest possible route. When we work on the more complicated circuits, we will give detailed instructions on exactly where to place each important lead; but during these early experiments, we will leave you on your own as much as possible to give you all the practical experience we can.

When you build equipment from a schematic diagram, you should carefully check each circuit you wire to make sure it is wired correctly. Also make sure that each connection is properly soldered. Even if you learn to work from a schematic, the equipment you build will not work properly unless all connections are properly soldered. Many people waste a great deal of time because of careless wiring and poorly soldered connections, which could easily have been spotted if a little extra time had been taken to check the work. Start right now by checking each circuit you wire against the schematic diagram and by checking each soldered connection you make. These are good habits, and the sooner you acquire them the better.

Experimental Procedure: For this experiment, in addition to the chassis with the solder lug and terminal strips, you will need the following:

1 1000-ohm resistor
1 22,000-ohm resistor
1 100,000-ohm resistor
2 1/4" X 4-40 screws
2 4-40 hex nuts
1 Etched circuit board (EC24)
Hookup wire
Solder

Use the resistor color code chart shown in Fig. 33 to help identify the three resistors used in this experiment.

Check your experimental chassis and make certain that the terminals are clean and all excess solder has been removed. At the same time, check the tip of your soldering iron to be sure it is clean and well-tinned.

For this experiment, you will use the tube socket on your circuit board and the terminals on your chassis. You will mount the circuit board along the edge of the chassis and connect "jumper" wires from the tube socket terminals in the copper foil to the 7-lug terminal strip on the chassis.

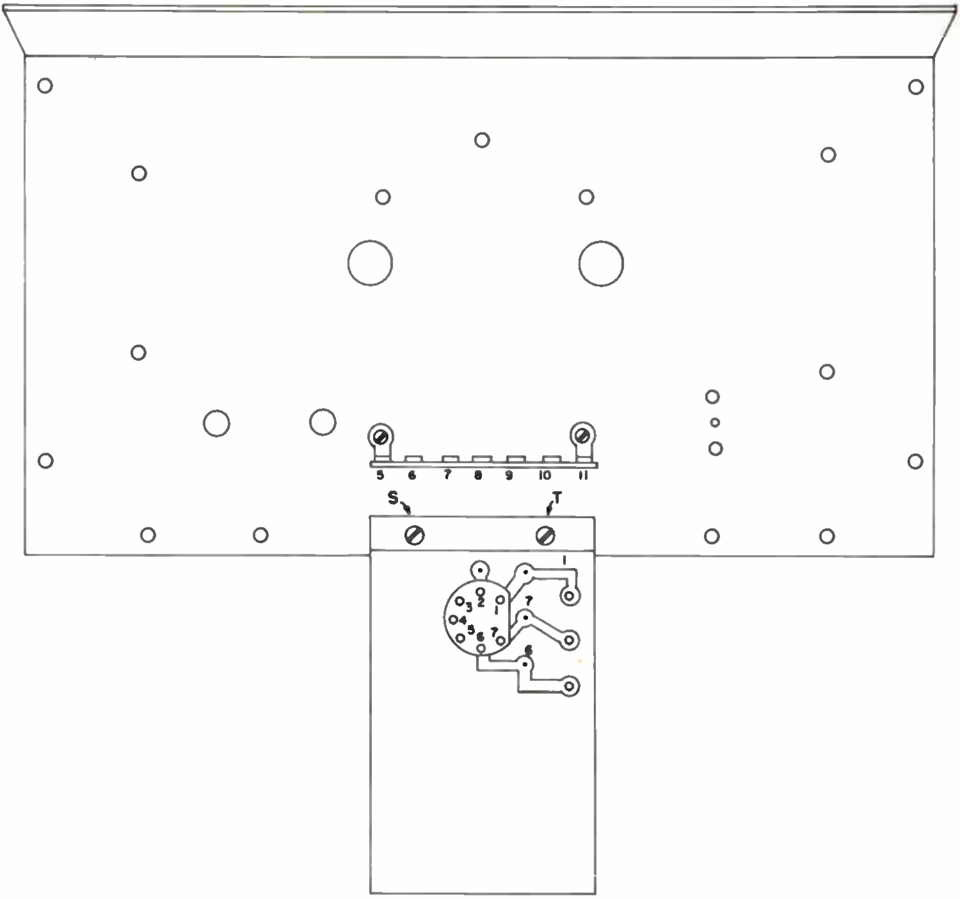


Fig. 4-2. Mounting the circuit board on the experimental chassis.

Mount the circuit board over holes S and T in the chassis (the holes are identified in Fig. 11 and Fig. 4-2). Position the circuit board over the edge of the chassis as shown in Fig. 4-2. Note that the tube socket is toward the chassis and the foil side of the board is turned upward. Attach the board with 1/4" X 4-40 screws through the mounting holes in the circuit board and chassis. Attach two 4-40 nuts and tighten.

The pins on the tube socket or tube are numbered from the blank space in a counterclockwise direction when viewed from the top. As shown in Fig. 4-3, pin 1 is at the right of the blank space, pin 2 is next, and so on. Pin 7 is to the left of the blank space. The pin in the center of the socket is not numbered. We will be primarily interested in pins 1, 6, and 7 of the socket. Connections to these holes are labeled on the foil side of EC24.

Refer to Fig. 4-4 as you make the following connections. Connect a short length of hookup wire from the hole in the foil which connects to pin 1 of the tube socket to terminal 8 on the 7-lug terminal strip. Remove about 1/4" insula-

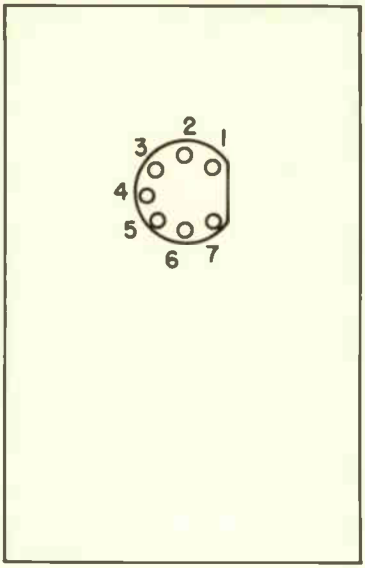


Fig. 4-3. Identifying the tube socket pins on the etched circuit board.

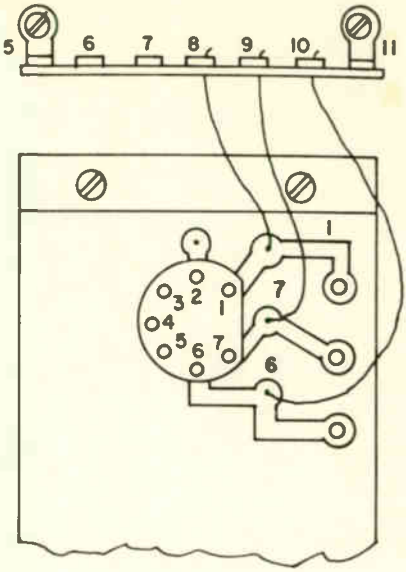


Fig. 4-4. Wiring connecting the tube socket to the terminal strip.

tion from each end of the wire. Slip the end of the wire through the hole in the circuit board from the foil side and solder to the foil.

Similarly, connect a short length of hookup wire from the hole in the foil at pin 7 to terminal 9.

In the same manner, connect a short length of hookup wire from the hole in the foil at pin 6 to terminal 10.

We often refer to a terminal or a conductor connected to a tube socket pin by the tube pin number or even by the element of the tube connected to that pin when a tube is inserted in the socket. Thus, the terminals on the chassis may be identified by the tube socket pin numbers, or as the grid, cathode and plate terminal of the 6C4 tube.

When working from schematic diagrams, remember that ground symbols indicate connections to the common return point (the chassis in this case) and that these connections can be made to anything that is connected to the chassis electrically. As your chassis is presently set up, you can use terminals 1, 5, 11, and 15 as ground connections.

If you are connecting two or more leads to a given point, do not solder until all leads are in position.

In this experiment, you are to wire a circuit directly from a schematic diagram. The diagram you are to use is shown in Fig. 4-5. The tube socket pins are indicated by the open circles nearest the tube symbol. All of the other terminals, which are shown by black dots, represent terminals on the terminal strip.

Before mounting a part, make a trial fit to determine where the part should be located. Sometimes this technique is used by experienced technicians in order to get a neat layout and prevent undue crowding of parts.

Step 1: To mount resistor R_1.

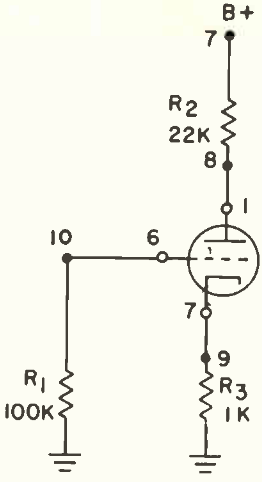


Fig. 4-5. Circuit used in Step 1.

First, find R_1 on the schematic diagram in Fig. 4-5. Notice that it is a 100,000-ohm resistor. Select a 100,000-ohm resistor from among the parts you have collected for this experiment.

From the schematic, you can see that R_1 is connected between pin 6 of the tube socket and ground. Because these connections will be made on the terminal strip, the connection will be made to terminal 10 and a ground terminal.

As stated earlier, there are four places where you can make your ground connection. The solder lug, terminal 1, and the mounting feet of the terminal strips, terminals 5, 11 and 15, are bolted directly to the chassis. Thus, they make electrical contact with the chassis and can be used for ground connections.

Connect one end of the 100,000-ohm resistor to terminal 10 and connect the other end to whichever ground point you find to be most convenient. Bend the resistor leads so that they do not touch the chassis. Also, they should not make contact with any other terminals. Solder terminal 10. Do not solder the ground terminal because you may want to make other connections to it.

Step 2: To mount resistor R_2.

Find resistor R_2 on the schematic diagram. You will see that it is a 22,000-ohm resistor (indicated by 22K on the diagram). You can also see that R_2 is connected from pin 1 of the tube socket, which is the same as terminal 8 on the terminal strip to terminal 7. Terminal 7 is marked "B+" on the schematic. Connect one lead of the 22,000-ohm resistor and solder these connections.

Step 3: To mount resistor R_3.

R_3 is a 1000-ohm resistor. On the schematic, R_3 is between pin 7 of the tube socket and ground.

Install the resistor between terminal 9 on the terminal strip (which is electrically the same as pin 7) and ground. You will have to choose a ground terminal. There are no more connections to be made. Thus, you can solder all connections which you have not yet soldered.

Step 4: To check your work.

After all wiring is in place, check your work against the schematic diagram. This check should now show:

1. A 100,000-ohm resistor between tube socket pin 6 and a ground terminal.
2. A 22,000-ohm resistor between tube socket pin 1 and terminal 7.
3. A 1000-ohm resistor between pin 7 of the tube socket and ground.

Discussion: In this experiment, you have gained experience in working from a schematic diagram. You have practiced reading resistor color codes, and you have again practiced making solder connections. You will use each of these skills every time you work on any electronic equipment.

After you have looked over your work to be sure that it is electrically equivalent to the circuit shown in Fig. 4-5, turn to the back of this manual. On page 77 you will see Fig. 4-6. This shows two ways in which you might have arranged your parts. However, these are not the only possible ways to mount the parts. As long as your arrangement is electrically the same as Fig. 4-5, you have done the experiment correctly.

Instructions For Statement No. 4: After carefully checking your work, answer the statement here and on your Report Sheet. Then unsolder the connections and remove the resistors. Disconnect the three jumper wires from the terminal strip and from the circuit board. Remove the circuit board from the chassis, clean the holes, and put the board aside. Finally, clean the resistor leads and terminals so that they will be ready for use in later experiments.

Statement No. 4: When I wired the circuit used in this experiment, I connected the 22,000-ohm resistor to the:

[✓ *(1) plate*]
(2) cathode
(3) grid

terminal of the tube socket.

Learning to Use A Meter

An electric current is invisible, odorless and tasteless. In other words, we cannot tell that a wire is carrying current unless we use some special means of detecting it.

Although a bell or light bulb can be used to show the presence of current, neither of these devices will indicate how much current is flowing. The current in the circuit must be at a certain level before the bell will ring or the bulb will light. For example, the light bulb will light to full brilliance when its greatest current is flowing through it. As the current is decreased, the light will grow dimmer. Finally, it will reach a point where the light will give no visual indication of current, even though current may still be present in the circuit. Something is needed that will show not only whether there is current flowing, but also how much current is flowing. A meter will do both of these jobs.

MEASURING CURRENT

A meter that is used to measure current is known as an ammeter. An ammeter indicates current in amperes. The ampere, however, is much too large a unit for most measurements in electronics, so we use a meter that indicates either milliamperes (ma) or microamperes (μa). A milliampere equals one-thousandth of an ampere and a microampere equals one-millionth of an ampere. Such meters are called milliammeters and microammeters. They are made the same and operate in the same manner as an ammeter. The only difference is that the milliammeter and microammeter are much more sensitive and will respond to much smaller currents.

The meter you will use in your experiments has a range of 0 to 200 microamperes. This means that a full scale reading on the meter indicates that 200 microamperes are flowing through the meter. When the meter pointer is at half scale, half of 200 microamperes or 100 microamperes are flowing through the meter. When the meter pointer is at 1/10th scale, 20 microamperes are flowing through the meter.

PREPARING THE METER

The meter supplied in this kit is an extremely delicate instrument. It contains a jewel movement similar to that of a fine watch. Therefore, the meter must be handled with care at all times. We cannot replace any meter that has been damaged through careless handling or improper usage. If you follow carefully the instructions given, you will have no trouble with the meter. However, if you fail to follow the instructions, you may damage your meter and have to replace it.

The meter case is plastic. It can easily be scratched with a screwdriver or similar tool, or by scraping it across your workbench. Also, the plastic can be permanently damaged by heat. Be sure that you do not accidentally touch the soldering iron to the meter case.

While you are performing these experiments, the meter will be left in its box. You will connect wires to the meter terminals so that you will have easy access to the meter.

You will need the following:

- 2 Large solder lugs (LU7)
- 1 Meter (ME21)
- 2 Diodes (SR12)
- Hookup wire
- Solder

Your meter is supplied with mounting hardware and two large nuts for each terminal. These parts are in an envelope in the meter box. Save all of the hardware as you will have need for it later.

To prepare the meter, place a soft pad or towel on your workbench. Next, remove the meter from the box and place the meter carefully on the pad or towel, face down, and with the top of the meter away from you.

Remove the wire from the meter terminals. The terminals were shorted together to prevent damage to the meter during shipment. If the meter is shaken or dropped, the physical movement will cause the meter pointer to move. A voltage is generated in the coil attached to the pointer. The short circuit across the meter terminals permits the current to flow through the terminals and back through the coil. This cancels the tendency of the coil to move and protects the meter from violent pointer swing.

You will now attach the large solder lugs to the meter terminals. First, attach a large nut to one of the terminals and run it all the way down. Then slip a large solder lug over the terminal and secure it with another nut. Position the solder lug so it points toward the bottom of the meter case and tighten the nut. Hold the lower nut with a small wrench or pliers and tighten the outer nut. Do not allow the terminal to turn, since this could damage the connection inside the meter case.

In a similar manner, attach two nuts and a solder lug to the other meter terminal and tighten the nuts.

Now you will identify the lugs on the back of the meter. The one on the left as you face the back of the meter is the positive, or plus terminal of the meter; the one on the right is the negative or minus terminal. The terminals may be further identified by plus or minus signs stamped on the plastic or on the ends of the screws or "POS" and "NEG" printed near the terminals.

Examine the two diodes supplied with this kit. Refer to Fig. 3-3 to help you identify the cathode leads.

Connect the lead at the cathode end of one diode to the positive terminal of the meter. This is diode D_1 in Fig. 34. Slip the end of the lead through the lug attached to the terminal. Do not solder at this time. Slip the anode lead of D_1 through the negative terminal lug.

Connect the second diode, D_2, to the meter terminals also, but with the opposite polarity. Slip the cathode lead through the negative terminal lug and the anode lead through the positive terminal lug. Do not solder at this time.

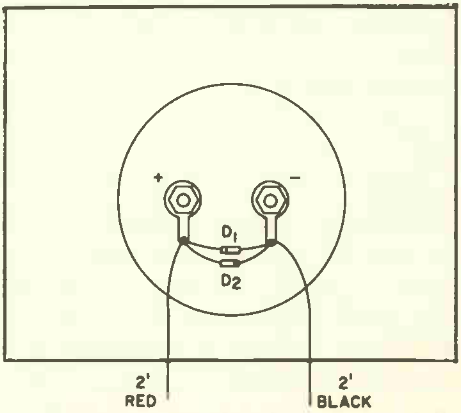


Fig. 34. Connections to the meter movement.

Prepare 2-foot lengths of red and black hookup wire. Remove about 1/4" of insulation from each end of each wire.

Connect the 2-foot length of red hookup wire to the positive meter terminal lug. Check to see that all three leads are through the hole in the terminal; then solder the connection. Be sure all three leads are soldered. After the solder cools, test the connection.

In a similar manner, connect and solder the length of black hookup wire to the negative meter terminal lug. Compare your wiring with Fig. 34 to see that you have done the work correctly.

Next, you will connect the meter leads to terminals on your chassis. Refer to Fig. 35. Connect the red lead from the meter to terminal 14. Connect the black lead from the meter to terminal 12.

Connect a 6" length of hookup wire from terminal 14 to terminal 10. Solder terminal 14.

In order to simplify the instructions, we will call terminal 10 the "positive meter terminal" and we will call terminal 12 the "negative meter terminal."

Put the meter in its box, face up. Do not attempt to make any measurements with your meter until instructed to do so.

The diodes, which you connected to the meter, are used to help protect the meter movement from excessive current. When a voltage of about .6 volt is present, one of the diodes will conduct and provide a low resistance path around the meter movement. We use two diodes connected with the opposite polarities to provide protection regardless of the polarity of the excessive voltage.

In normal operation, the voltage across the meter terminals will not exceed .15 volt. Therefore, the diodes have no significant effect on the operation of the meter unless excessive voltage is applied.

SETTING THE METER POINTER TO ZERO

The meter pointer should rest directly

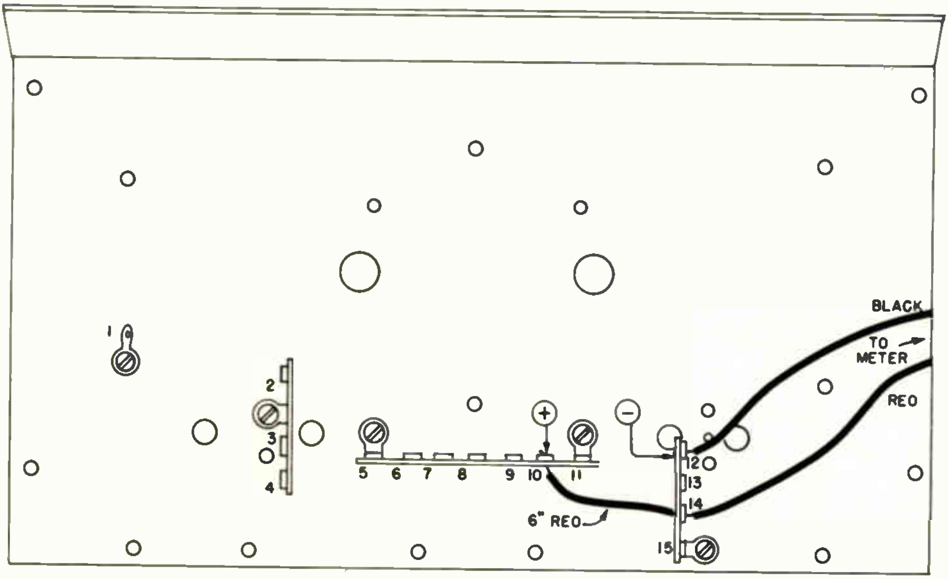


Fig. 35. The meter leads connected to terminals 12 and 14 with a jumper from 10 to 14.

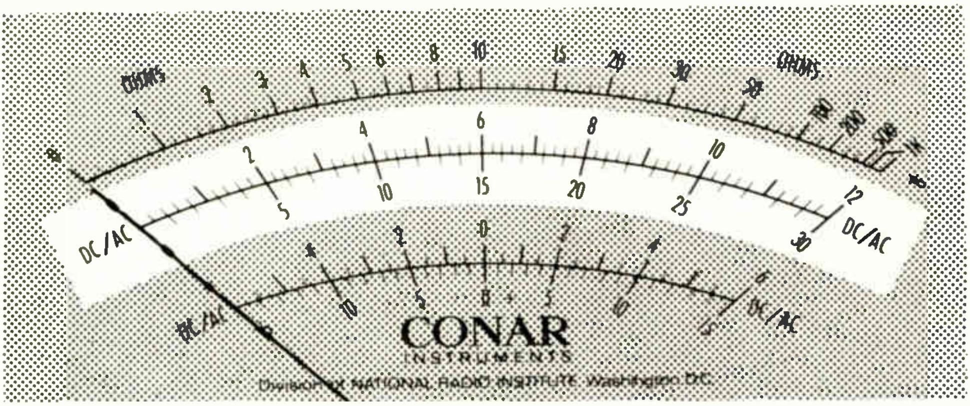


Fig. 36. The 0-12 and 0-30 volt scales on your meter.

over zero as shown in Fig. 36 when the meter is not in use. To set the pointer to zero, use a screwdriver blade that fits in the plastic screw slot on the meter face. Too small or too large a blade can damage the screw. Turn this screw, and notice that the meter pointer can be placed to the right or to the left of zero. Leave the screw adjusted so the meter pointer is over the zero mark. It is unlikely that you will have to make this adjustment again.

READING THE METER

The first time you look at the face of the meter you received in this kit, you may think that the meter is complicated and that it will be difficult to read. As a matter of fact, it is no more difficult to read a meter than it is to tell time on a clock. Of course, a meter may be something new to you, and it will take some practice to learn how to read it quickly. However, it will not be long before you will be able to read it at a glance.

At this time we will concentrate on the 0 to 12 and 0 to 30 volt scales. As you will see, the two scales may often be used together to help you obtain precise readings. These two scales are shown in white in Fig. 36. The 0 to 12 volt scale is the upper scale and has the numbers 0, 2, 4, 6, 8, 10 and 12 printed in black. The 0 to 30 volt scale is the lower scale and has the

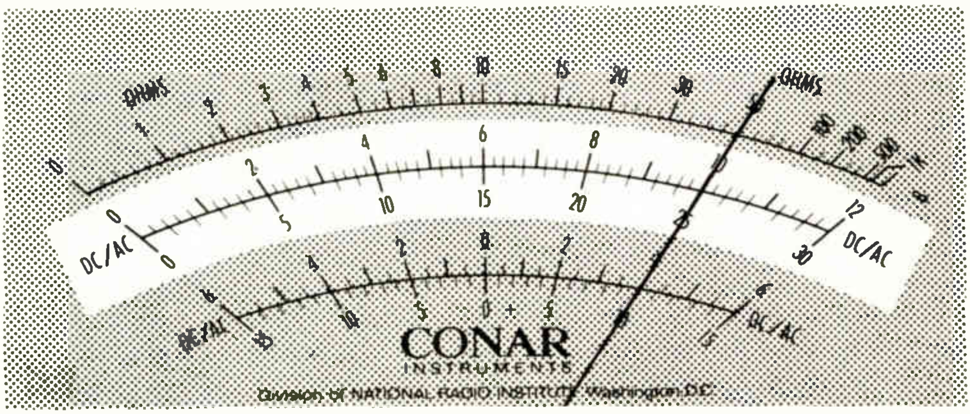


Fig. 37. A meter reading of 25 or 10.

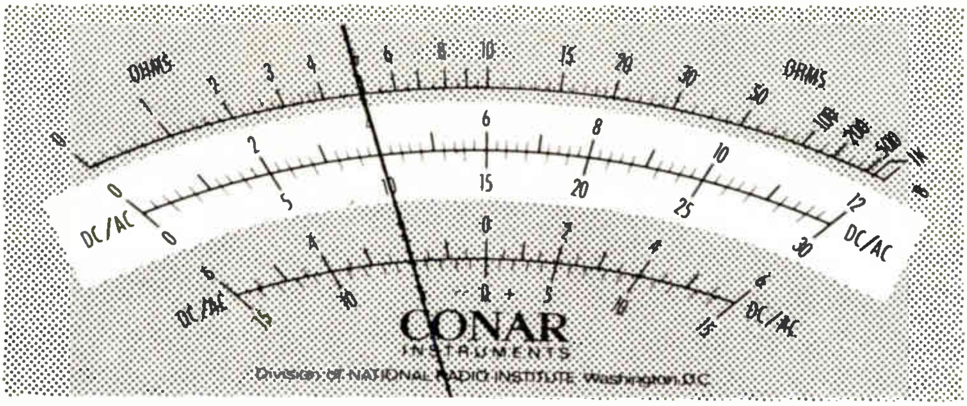


Fig. 38. A meter reading of 10 or 4.

numbers 0, 5, 10, 15, 20, 25 and 30 printed in black. Notice that the 0 to 12 volt scale has several short marks as well as some longer unnumbered marks. The 0 to 30 volt scale has four short unnumbered marks between each number.

Now look at the meter shown in Fig. 37. In this case the pointer is indicating 10 on the 0 to 12 volt scale and shows 25 on the 0 to 30 volt scale. If the pointer is as shown in Fig. 38, the reading would be 10 on the 0 to 30 volt scale and 4 on the 0 to 12 volt scale. These readings are quite easy to determine, as you can see, but what happens if the pointer is somewhere between the numbers on the scale?

Look at the scale shown in Fig. 39. Now the pointer is over one of the short marks of the 0 to 12 volt scale, but is between two short marks on the 0 to 30 volt scale! To read this value, note that on the 0 to 12 volt scale there are nine marks (or ten spaces) between 6 and 8; eight short marks and one long mark. The long mark represents 7 volts, and each short mark represents 0.2V. The pointer in Fig. 39 is on the third short mark following the 6 volt mark. Since each short mark is 0.2V, the pointer shows a reading of 6.6 volts.

Now, what is the reading of Fig. 39 on the 0 to 30 volt scale? First, notice that

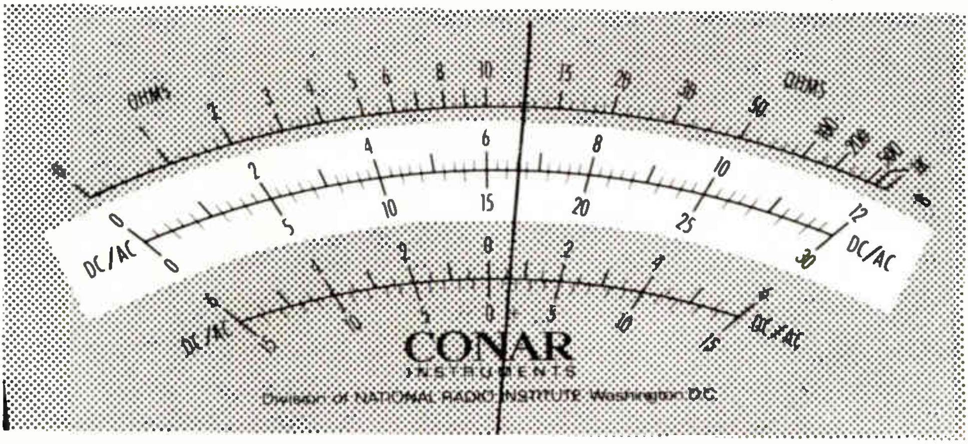


Fig. 39. Another sample meter reading.

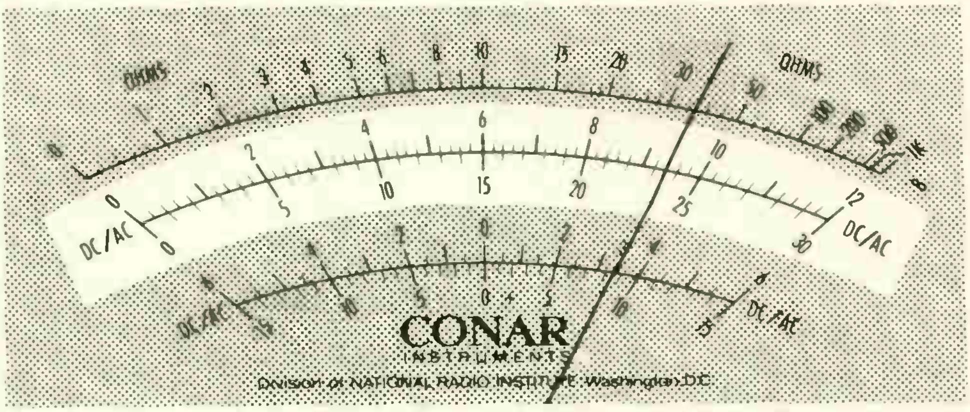


Fig. 40. Study this meter reading and see if you can tell what it is.

between 15 and 20 there are four short marks. Each mark, therefore, represents one volt. The pointer is halfway between the first and second marks following 15 so the reading is 16.5 volts. You can tell that the pointer is exactly halfway between the two marks by looking at the upper (0 to 12 volt) scale. On this scale, every other mark falls exactly halfway between the one volt marks on the 0 to 30 volt scale. This means that while the 0 to 30 volt scale is marked in one volt steps, you can determine readings to one half a volt by looking at the divisions on the 0 to 12 volt scale.

Let's look at another example. Take a look at the scale shown in Fig. 40. Using the reasoning that we applied in the previous examples, can you tell what the reading would be on the 0 to 12 and 0 to 30 volt scales? If you have trouble, go back and reread the material in the previous paragraphs. After careful study you should have no difficulty in seeing that the readings are 9.4 volts and 23.5 volts respectively on the 0 to 12 and 0 to 30 volt scales.

There is always the possibility that the pointer will not fall precisely on one of the short marks of the 0 to 12 volt scale. How are these values read? Take a look at Fig. 41. Notice here that the pointer is halfway between the second and third short marks after 4 on the 0 to 12 volt

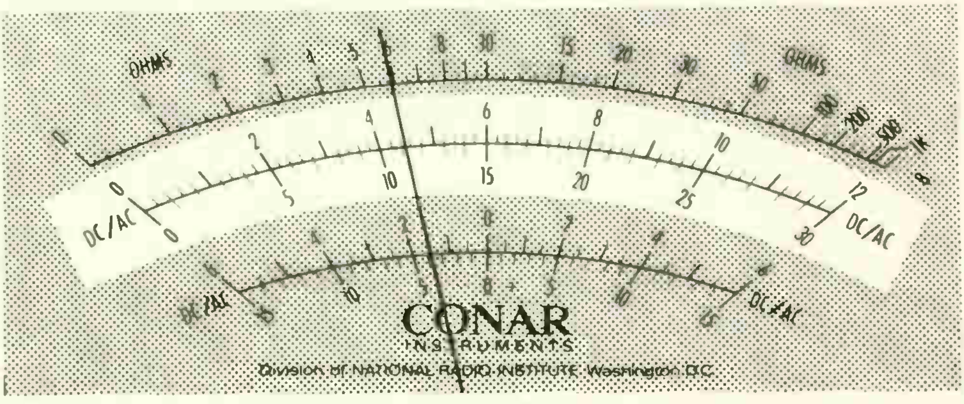


Fig. 41. Here is another meter reading for you to practice on.

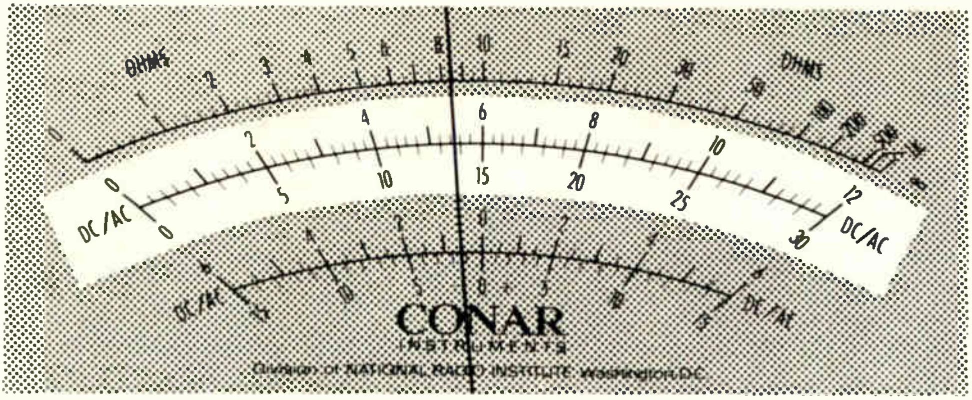


Fig. 42. What is the indication on this meter?

scale. This would be a reading of 4.5 volts. On the 0 to 30 volt scale it is just as easy. The pointer falls one fourth of the way between the first and second mark after 10, so the reading is 11.25 volts.

As a final example, try your hand at reading the two values indicated in Fig. 42. Again, the pointer does not fall on any of the scale marks of either scale. Let us see how close we can come to reading the meter by applying what we have already learned. On the 0 to 12 volt scale, the pointer is between 5 and 6. We can be more exact than that; it appears to be halfway between the second and third marks following the (unmarked) 5 volt mark. The first mark is 5.2 volts, the second mark is 5.4 volts and the third mark is 5.6 volts. Therefore the reading is between 5.4 and 5.6 volts. How much, is the question. The pointer falls about halfway between 5.4 and 5.6 volts so we would call it 5.5 volts. There is, of course, some uncertainty in this reading. For the purposes of your experiments, you would read it as 5.5 volts.

What reading does Fig. 42 represent on the 0 to 30 volt scale? Well, it is somewhere between 10 and 15 volts. Each short mark represents one volt, so the reading would be between 13 and 14 volts. Remember that the short mark on the *upper* scale (0 to 12 volts) is exactly halfway between the 13 and 14 volt marks, or in other words represents 13.5 volts. The pointer falls to the right of this mark so the reading must be between 13.5 and 14.0 volts. We would probably call this 13.75 volts; any value from 13.7 to 13.8 volts would be sufficient.

Building A Simple Series Circuit

You have already studied Ohm's Law and you know that there is a definite relationship between the voltage, current and resistance in a circuit. In Experiment 5, you will see just what happens to the current when you change either the resistance in the circuit or the voltage applied to the circuit. Before you begin Experiment 5 you will prepare the chassis by installing some parts on it. Then, when you begin Experiment 5 you will add some more parts and perform the Experiment.

In addition to your meter and chassis, you will need:

- 2 4.7K-ohm resistors (yellow-violet-red-silver)
- 1 6.8K-ohm resistor (blue-gray-red-silver)
- 1 1.5-volt flashlight cell
- Black hookup wire
- Red hookup wire
- Solder

Inspect the tip of your soldering iron. If necessary, file and retin the tip.

You will connect the three resistors to terminals 7, 8, 9 and 10 on your chassis. The chassis with the resistors in place is shown in Fig. 43. Begin by connecting one lead of a 4.7K-ohm resistor to terminal 10. (There should already be a red wire connected to terminal 10.) Temporarily solder the lead and the red wire to terminal 10. Bend the resistor leads near the body of the resistor and push the free lead through the slot in terminal 9. Connect one lead of another 4.7K-ohm resistor to terminal 9. Solder terminal 9. Connect the other lead of this resistor to terminal 8. Connect one lead of the 6.8K-ohm resistor from terminal 8 to terminal 7 as shown in Fig. 43. Solder terminal 8.

Remove 1/4" of insulation from each end of a 10" length of red hookup wire. Connect and solder one end to terminal 7. Leave the other end free.

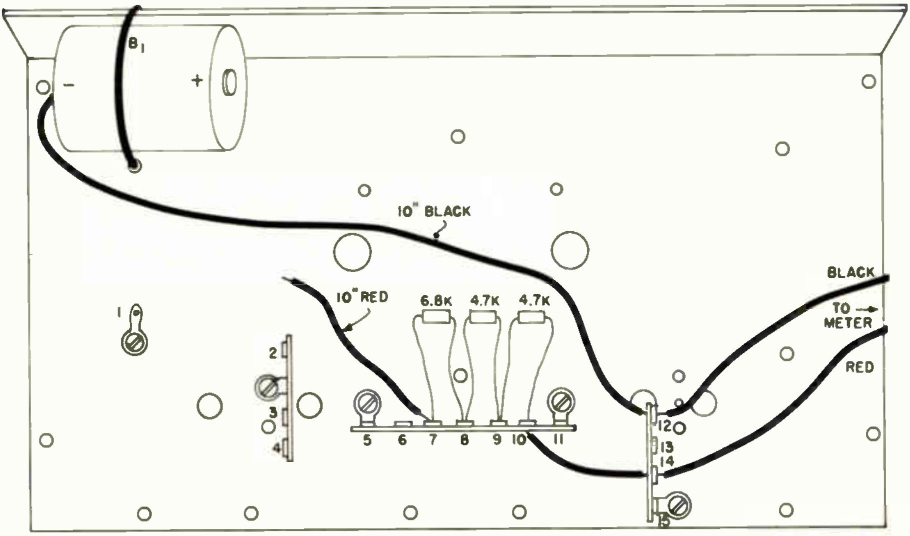


Fig. 43. Experimental chassis wired for Experiment 5.

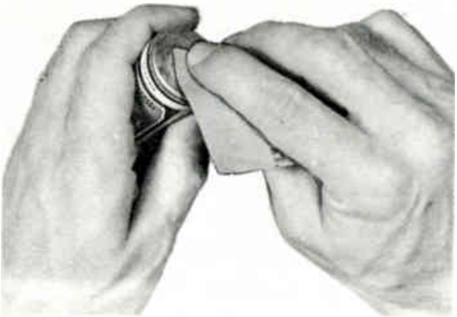


Fig. 44. How to clean the center of the bottom of a flashlight cell with a piece of sandpaper.

You should now have three series-connected resistors going from the positive meter terminal (terminal 10) to terminal 7. The total resistance between terminal 7 and the positive meter terminal is the sum of the values of the three resistors; a total of about 16,000 ohms.

You now have a 0-200 microampere meter with approximately 16,000 ohms in series with it.

In order to measure current, your meter must be connected to a source of voltage with the proper polarity. The positive terminal of the voltage source must always be connected to the lead or circuit point that goes to the positive meter terminal.

At first, we will use a flashlight cell which produces 1.5 volts dc as a source of voltage. To do this, you are to connect a wire from the negative meter terminal, terminal 12, to the negative battery terminal. Notice that one end of your flashlight cell has a raised portion while the other end is flat. The negative battery terminal is the end with no raised section. Clean a spot in the middle of the bottom of the cell with a piece of fine sandpaper, as shown in Fig. 44.

Be sure that your soldering iron tip is clean and hot. Then, hold the end of your roll of solder on the negative terminal of the cell and touch your soldering iron to the solder. Rub the iron around so that the terminal becomes well-tinned.

Now cut a 10" length of black hookup wire and remove 1/4" of insulation from each end. Place one end of the 10" length black hookup wire on the tinned area of the negative terminal of the cell. Touch the tip of your soldering iron to the wire and the tinned portion of the cell. The solder should melt and run over the wire. Remove the heat and allow the joint to cool. If the solder does not flow smoothly over the wire, add a little more solder as you heat the connection.

If you like, you can use a piece of hookup wire to secure the cell in place along the bend in the chassis as shown in Fig. 43. Note that the negative terminal is toward the left side of the chassis.

Fig. 45. Schematic symbol for a battery.

The symbol we use on schematic diagrams to represent a battery is shown in Fig. 45. Each pair of lines represents one cell of the battery. The short wide line represents the negative terminal and the longer thin line represents the positive terminal. To represent one cell, we use only one pair of lines; but to represent several cells, we do not try to show the exact number, as two or more pairs are sufficient.

EXPERIMENT 5

Purpose: To show that current flowing in a series circuit will change when the

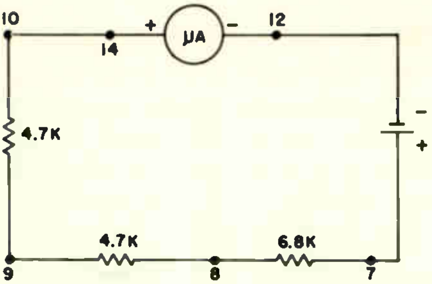


Fig. 5-1. The circuit you will use in Step 1 of Experiment 5.

resistance in the circuit or the voltage applied to the circuit is changed.

Introductory Discussion: Although the circuit you will use in this experiment is a simple circuit, it will act in the same way that a more complex circuit would act when either the resistance or voltage is changed.

This experiment will demonstrate Ohm's Law, which is one of the most important laws you will study. Do each step of the experiment carefully and make sure you understand exactly what you are doing and what the changes in current that you observe mean.

Experimental Procedure: In this experiment, in addition to the meter, chassis and the circuit you have just wired, you will need the following:

1 1.5-volt flashlight cell
Hookup wire

The first circuit you will use is shown in Fig. 5-1. When you read the meter, use the 30-volt scale which you practiced reading previously.

Step 1: To connect 1.5 volts across the meter and series resistor combination.

Touch the red wire from terminal 7 to the positive terminal of the flashlight cell. This closes the circuit and causes current to flow.

Observe the pointer on your meter. It should be slightly below one-half scale. If you get no reading, look for a bad connection or a short circuit. Check to be sure that your circuit is wired as shown in Fig. 5-1. Trace the wiring from terminals 12 and 10 back to the terminals on the meter. Also check for a short circuit between the meter terminals or leads.

The meter scale which you are using in this experiment (Fig. 5-2) is the 0 to 30 volt scale. However, in this experiment you are using this scale only as a relative indication of the amount of current in the circuit. The meter indicates a current of about 100 microamperes, since you know that a full scale reading (30) repre-

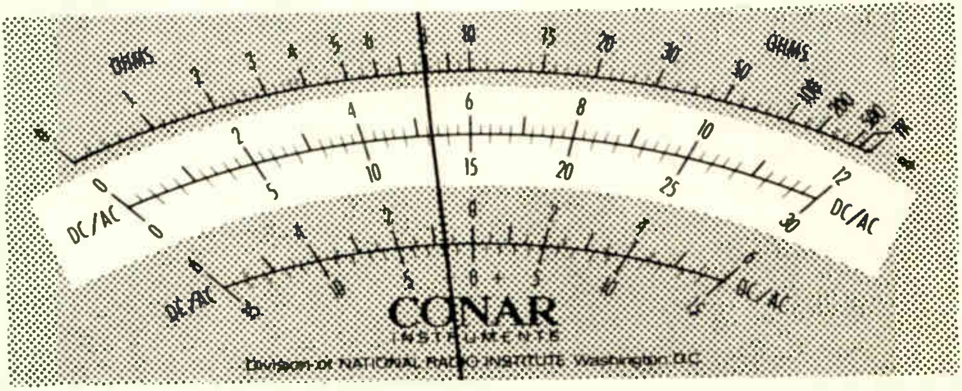


Fig. 5-2. The meter reading of Step 1 should be approximately 13 on the 0-30 scale.

STEP	READING
1	13,5
2	27,5
3	23,2

Fig. 5-3. Record your reading for Experiment 5 here.

sents a current of 200 microamperes.

In later experiments you will learn that the 0 to 30 volt scale will also be used to indicate 0 to 3 volts, and 0 to 300 volts. The 0 to 12 volt scale will also be used to indicate ranges of 0 to 1.2 volts, 0 to 120 volts and 0 to 1200 volts. For the time being, however, you need only be concerned with relative scale indications on the 0 to 30 volt scale. Read the meter carefully and write the reading of the meter in the space provided for Step 1 in Fig. 5-3. Remove the red wire from the positive terminal of the flashlight cell to open the circuit.

Step 2: To determine the effect of increasing the voltage in a series circuit.

To do this, you will connect another flashlight cell in series with the cell you used in Step 1. This is shown in the schematic diagram in Fig. 5-4.

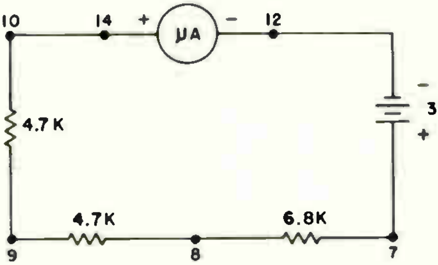


Fig. 5-4. Circuit to use for Step 2.

Clean the positive terminal of the second flashlight cell with a piece of fine sandpaper. Hold your soldering iron on the terminal and apply solder. Melt

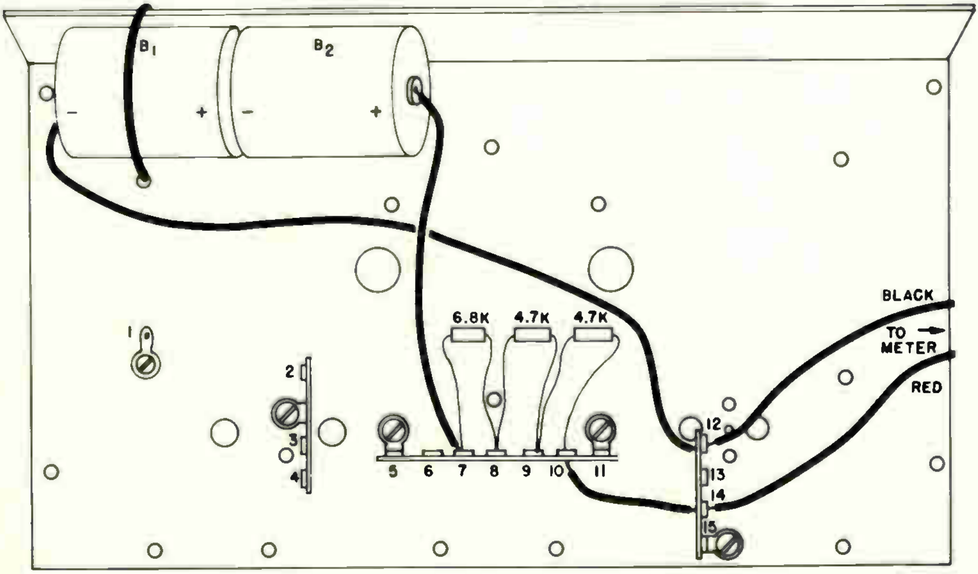


Fig. 5-5. Series resistor with 3-volt battery.

enough solder on the terminal to tin it. Rub the tip of the iron around so that the terminal is well-tinned.

Place the free end of the red wire connected to terminal 7 on the tinned area of the positive terminal of this flashlight cell and apply heat to solder the wire to the terminal. Use additional solder if necessary.

Now, to complete the circuit, hold the positive end of the first flashlight cell against the negative terminal of the second flashlight cell, as shown in Fig. 5-5. This places the two 1.5-volt cells in series, thus forming a 3-volt battery.

The meter pointer should swing to the right to just under 30 on the 30-volt scale. Look at the meter carefully, read the value as closely as you can, and write the reading in the space reserved in Fig. 5-3.

Step 3: To show that the amount of current will change when the resistance is changed.

The circuit you will use is shown in Fig. 5-6. Unsolder the red wire from the positive terminal of the second flashlight cell and from terminal 7 and set the cell to one side. Solder one end of the red wire you just removed to terminal 8.

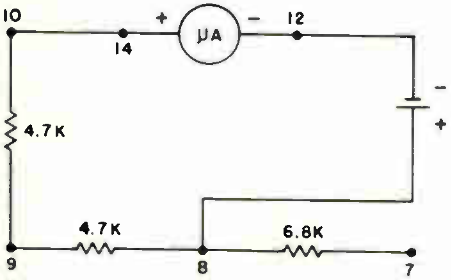


Fig. 5-6. Circuit you use for Step 3.

Touch the free end of the red wire to the positive terminal of the flashlight cell on the chassis. You now have a total of about 9,400 ohms in the circuit with a source voltage of 1.5 volts. Read the meter and record your readings in the space for Step 3 in Fig. 5-3.

Discussion: In this experiment, you have seen what happens in a series circuit when the voltage or resistance is changed. You should have a reading of something less than 15 for Step 1. When you doubled the voltage in the circuit by adding a second flashlight cell, you should have obtained a reading of about two times the original reading. In other words, when you double the voltage supplied to the circuit, the current in the circuit doubles. From this, you can see that there is a definite relationship between voltage and current in a series circuit.

In Step 3, when you reduced the resistance in the circuit, you should have found that the current was greater than in Step 1. This shows that if you reduce the resistance in a series circuit, the current will increase. We could have shown that increasing the resistance will cause the current to decrease, but this should have been obvious from the steps that you have already carried out in this experiment.

Instructions For Statement No. 5: In order to complete this statement you must obtain one additional reading. You will find the current through a resistance of approximately 7,500 ohms connected across a voltage of 1.5 volts. To get this reading, wire the circuit shown in the schematic in Fig. 5-7. Connect a short length of hookup wire from terminal 7 to terminal 9. Solder both connections. Fig.

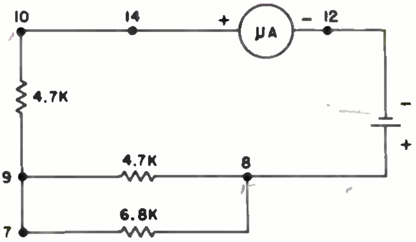


Fig. 5-7. Connect the free end of the resistors to the junction of the first and second resistors to get Statement answers.

5-8 shows the chassis wired according to Fig. 5-7. This places a 4,700-ohm resistor in parallel with the 6,800-ohm resistor. This combination is in series with the other 4,700-ohm resistor. Next, touch the red wire from terminal 8 to the positive terminal of the flashlight cell on the chassis.

Observe the meter reading on the 30-volt scale and answer the statement.

Remove the three resistors connected to terminals 7, 8, 9 and 10 and clean their leads so they will be ready for reuse. Also, disconnect and remove the short length of wire connecting terminals 7 and 9 and remove the 10″ length of red wire from terminal 8. Do not discard this wire as you can reuse it in later experiments. Do not remove any of the other wires.

Statement No. 5: When I touched the free end of the lead from terminal 8 to the 1.5-volt cell, I obtained a reading of approximately

(1) 15
(2) 30
(3) 10

EXPERIMENT 6

Purpose: To show how to connect resistors in parallel; and to show that the net resistance of a group of parallel-connected resistors is less than that of the smallest resistor in the group.

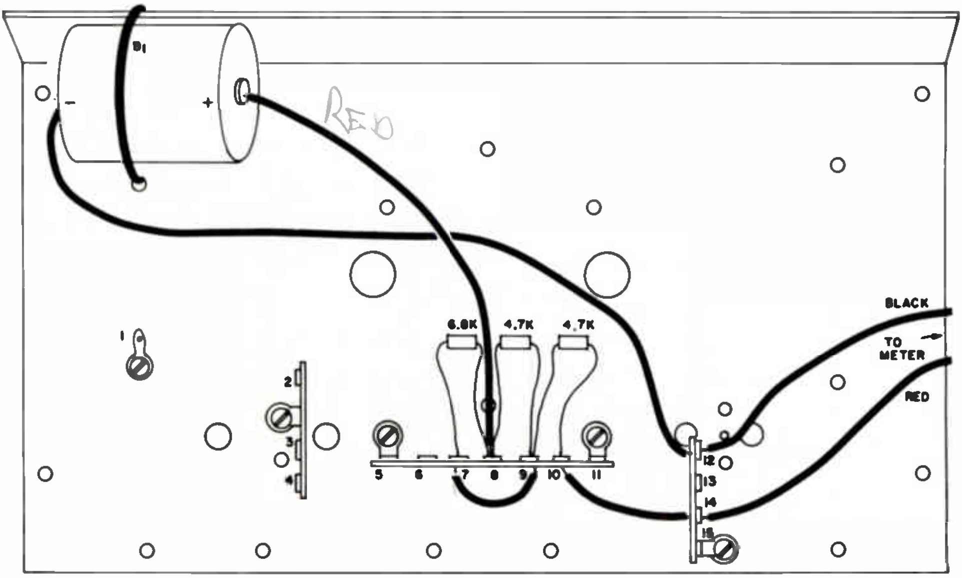


Fig. 5-8. Chassis arrangement for Statement 5.

Introductory Discussion: In the last experiment, you learned how to connect resistors in series with a source of voltage. When resistors or any other parts are connected across a voltage source, they are called a load. In a circuit of this type, each resistance, including that of the meter, can be considered as part of the total load resistance. Thus, the total load resistance is the sum of the individual resistances.

In this experiment we will show that loads can also be connected to the source voltage so that the entire source voltage is connected to each load. We will also show that when loads are connected in this manner, the net resistance of the combined load is less than the resistance of the smallest resistance in the group.

Experimental Procedure: In making these tests, you will use the following parts:

- **2 100,000-ohm resistors**
- **1 82,000-ohm resistor**
- **2 Flashlight cells**
- **Red hookup wire**

Since good connections will be required, we will solder leads to the batteries. To do this, clean the battery terminals (that you have not yet used) with a piece of sandpaper and tin them, as you learned to do in the last experiment.

Remove 1/2" of insulation from each end of an 8" length of red hookup wire. Place one end of one wire on the tinned area of the positive terminal of the cell connected to terminal 12. Touch the soldering iron to the junction. The solder on the tinned areas should melt and run over the wire. If necessary, add solder to get a good connection. Remove the heat, and let the joint cool. Solder the other end of the wire lead to the tinned area on

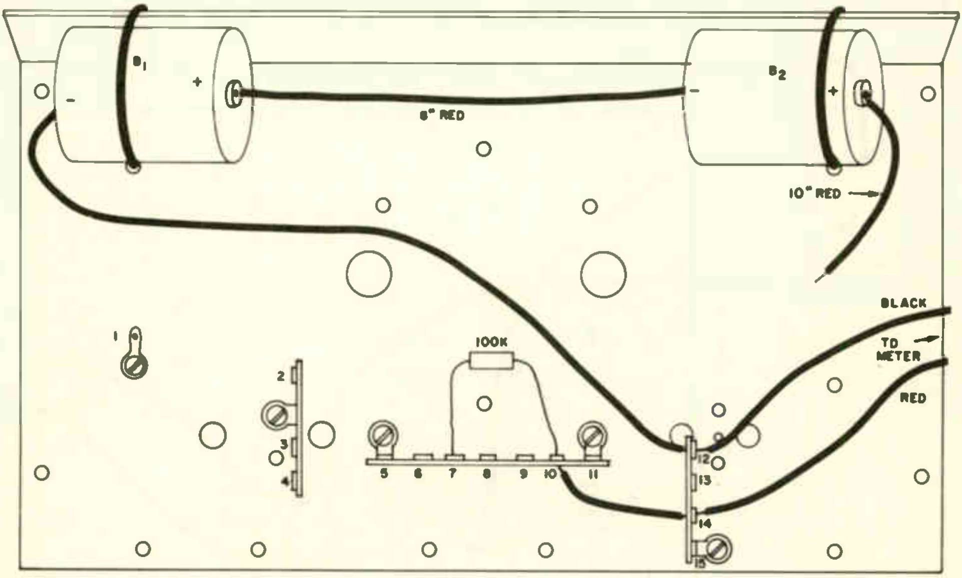


Fig. 6-1. Chassis wired for Step 1.

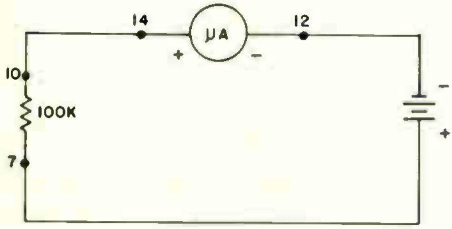


Fig. 6-2. Schematic diagram for Step 1.

the negative terminal of the second battery.

Secure the second battery to the right side of the chassis as shown in Fig. 6-1. You can pass a piece of string or hookup wire through the hole in the chassis and around the battery.

We will call the cell on the left side of the chassis B_1 and we will call the cell on the right B_2.

Locate the 10″ length of red hookup wire you used in the last experiment. Solder one end of this wire to the positive terminal of the flashlight cell, B_2. Leave the other end free.

You now have a 3-volt battery. The negative terminal of the 3-volt battery is the negative terminal of B_1 and is connected to terminal 12. The red wire connected to the positive terminal of B_2 is the "positive battery lead."

Complete the circuit shown in Figs. 6-1 and 6-2 by soldering a 100,000-ohm resistor between terminals 7 and 10.

Step 1: To get an indication of the current flowing with a 100,000-ohm resistor in the circuit.

Touch the free end of the positive battery lead, which is soldered to the positive terminal of B_2, to terminal 7. Read the meter indication on the 30-volt scale. The meter pointer should be in about the position shown in Fig. 6-3. Your reading may be somewhat higher or lower than the value shown in Fig. 6-3 because of normal tolerances in resistor values and the output voltages of different cells. Read the meter carefully and then remove the free end of the positive battery lead from terminal 7 to open the circuit. Record your reading in the space provided for Step 1 in Fig. 6-4.

Step 2: To connect a 100,000-ohm resistor in parallel with the resistor used in Step 1.

Clean the leads of the second 100,000-ohm resistor and connect it in parallel with the resistor used in the last

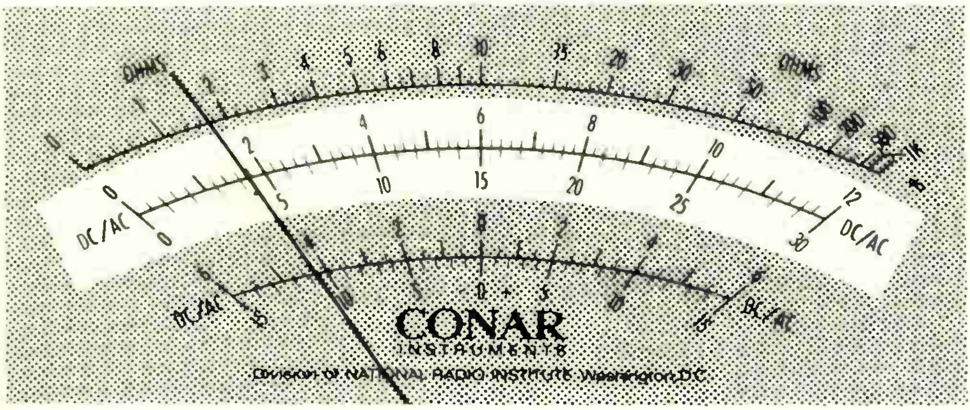


Fig. 6-3. Meter reading for Step 1.

STEP	READING
1	4.7
2	9.5
3	14.9

Fig. 6-4. Record your reading for Experiment 6 here.

step. You may solder the leads to terminal 7 and 10 or, if you prefer, you may solder the leads to the leads of the resistor already in the circuit. The circuit for this step is shown in Fig. 6-5.

Touch the positive battery lead to terminal 7 and read the meter on the 30-volt scale. Remove the positive battery lead after recording your reading in the chart in Fig. 6-4.

Step 3: To add an 82,000-ohm resistor to the parallel connected 100,000-ohm resistor.

Clean the leads of the 82,000-ohm resistor and solder it either to terminals 7 and 10 or to the leads of one of the resistors used in Step 2. The schematic diagram of the circuit for this step is shown in Fig. 6-6. Touch the positive battery lead to terminal 7 and note the reading on the meter. Open the connection after recording your reading in Fig. 6-4.

Discussion: In this experiment you have demonstrated what happens to the current in a circuit when resistors are connected in parallel. You should have discovered that as you added the second 100,000-ohm resistor to the circuit, your reading on the meter was about twice what it was with only one resistor in the circuit. When you added the third resistor, you should have found that the current increased still more.

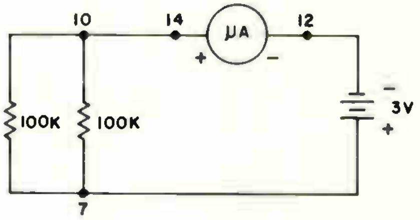


Fig. 6-5. Schematic diagram for Step 2.

You know from Ohm's Law that the amount of current that will flow in a circuit depends on the voltage applied to the circuit and the resistance in the circuit. In other words, I = E ÷ R. The value of E did not change; it was 3 volts throughout the entire experiment. Therefore, the change in current must have been entirely due to the change in resistance. In fact, the total resistance in the circuit decreased as you added more

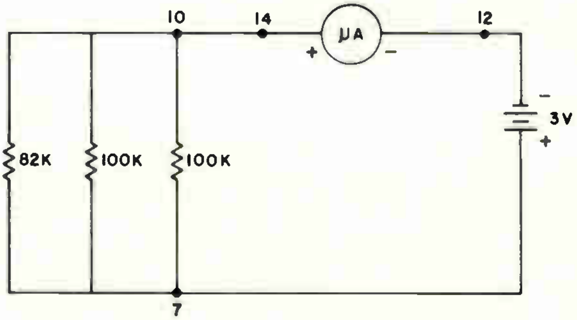


Fig. 6-6. Schematic diagram for Step 3.

resistors in parallel to produce the increase in the circuit current.

Of the three resistors used in this experiment, the 82,000-ohm resistor has the lowest resistance, and we will use this resistor by itself in the statement for this experiment.

Instructions for Statement No. 6: Remove all three resistors from terminals 7 and 10. Separate the resistors and reconnect the 82,000-ohm resistor to terminals 7 and 10.

Touch the positive battery lead to terminal 7 and note the reading on the meter. Open the circuit, and write the reading in the margin of this page. Answer the statement, and then disconnect the 82,000-ohm resistor. Clean and straighten its leads so that it will be ready for re-use. Leave all other connections alone as they will be used in the next experiment. Leave the two flashlight cells connected together and the lead from the negative terminal of the battery connected to terminal 12.

Statement No. 6: When I connected an 82,000-ohm resistor in place of the parallel group, the reading was:

(1) higher
[✓ *(2) lower*]

5.7

than the reading obtained in Step 3.

This indicates that the resistance of the parallel group was:

(1) more than
[✓ *(2) less than*]

that of the 82,000-ohm resistor by itself.

EXPERIMENT 7

Purpose: To show that the current is the same at every point in a series circuit.

Introductory Discussion: You already know that current in a circuit is the flow of electrons through the circuit. Electrons flow from the negative terminal of the voltage source, which is the battery in this experiment, through the load, and back to the positive terminal of the battery. Inside the battery, electrons flow from the positive terminal to the negative terminal.

In any series circuit, the current is the same throughout the entire circuit. In other words, if you connect a current-measuring instrument into the circuit to measure the current, it will not make any difference where you connect the instrument -- you will always get the same current reading. In this experiment you will demonstrate this. You will even show that the current flowing in the battery itself is the same as the current flowing in the external circuit.

Experimental Procedure: In this experiment, in addition to the meter, chassis and flashlight cells you will need the following parts:

1 100,000-ohm resistor
1 82,000-ohm resistor
1 22,000-ohm resistor
Hookup wire

Fig. 7-1 shows the circuit you will use for Step 1. This is the same setup used in

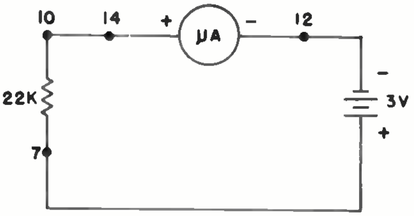


Fig. 7-1. Schematic of circuit for Step 1.

STEP	READING
1	20.5
2	20.5
3	20.5

Fig. 7-2. Record your reading for Experiment 7 here.

the last experiment. To construct the circuit, solder the leads of the 22,000-ohm resistor to terminals 7 and 10. When you have made these connections you should have:

(1) a wire from the negative battery terminal (negative terminal of B_1) to terminal 12,
(2) a wire connecting terminal 14 and terminal 10,
(3) a 22,000-ohm resistor connected from terminal 10 to terminal 7,
(4) a wire from the positive terminal of B_1 to the negative terminal of B_2, and
(5) a wire soldered to the positive battery terminal with the other end free. There should be no wire soldered to terminal 7.

If your circuit is properly wired, you may proceed with the first step.

Step 1: To measure the current leaving the battery.

Touch the free end of the positive battery lead to terminal 7. Read the meter on the 30-volt scale and record the reading in the space provided for Step 1 in Fig. 7-2. On the schematic in Fig. 7-1, you can see that the battery current flows from the negative battery terminal, through the meter to the resistor. It then flows through the resistor and back to the positive battery terminal.

Step 2: To measure the current returning to the battery.

Rewire the circuit as shown in Fig. 7-3. To do this, first unsolder and remove the red wire from terminal 10 to terminal 14. Unsolder the black negative battery lead from terminal 12. Solder the free end of the black wire to terminal 10. Connect and solder a length of hookup wire from terminal 7 to terminal 12.

Notice on the schematic in Fig. 7-3 that the meter is now between the resistor and the positive battery terminal.

Touch the free end of the positive battery lead to terminal 14 to complete the circuit. Read the meter on the 30-volt scale. Open the circuit after recording the reading for Step 2 in Fig. 7-2.

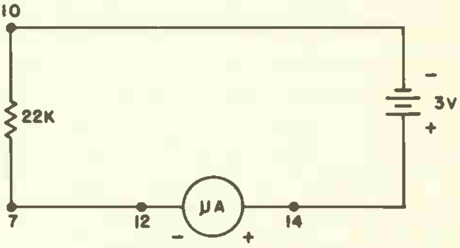


Fig. 7-3. Circuit for Step 2.

Step 3: To show that the current flowing inside the battery itself is the same as the current flowing in the external circuit.

The battery you are using in this experiment consists of two flashlight cells. Large batteries of the type used in earlier tube-type portable radios have voltages of 45 and 90 volts and are made up of groups of 1.5-volt cells, similar to flashlight cells. These are connected in series to get the required voltage. The more cells that are connected in series, the higher the voltage.

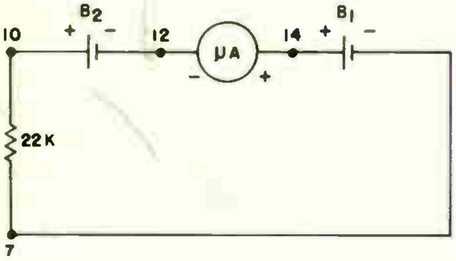


Fig. 7-4. Circuit for Step 3.

With an external circuit connected to the battery, you can measure the internal current in the battery by inserting a meter between any two adjacent cells.

To illustrate this in the experiment, wire the circuit shown in the schematic in Fig. 7-4. Fig. 7-5 shows a pictorial diagram of the wiring. Unsolder and remove the short length of hookup wire connected from terminal 7 to terminal 12.

Locate the wire connecting the two flashlight cells. Unsolder this wire from the positive terminal of B_1. Solder the free end of the wire to terminal 12.

Solder the negative battery lead to terminal 7.

Connect and solder a length of hookup wire from terminal 14 to the positive terminal of B_1. Check to see that your circuit is wired correctly.

Touch the positive battery lead (from B_2) to terminal 10 to complete the circuit. Read the meter carefully and open the circuit after recording your reading in the space provided for Step 3 in Fig. 7-2.

Discussion: In Step 3 of this experiment, the circuit is connected as shown in Fig. 7-4. Here the meter is actually placed between the two flashlight cells, and is measuring the current flowing from one cell into the second cell. Compare your readings for this step with your readings in Steps 1 and 2.

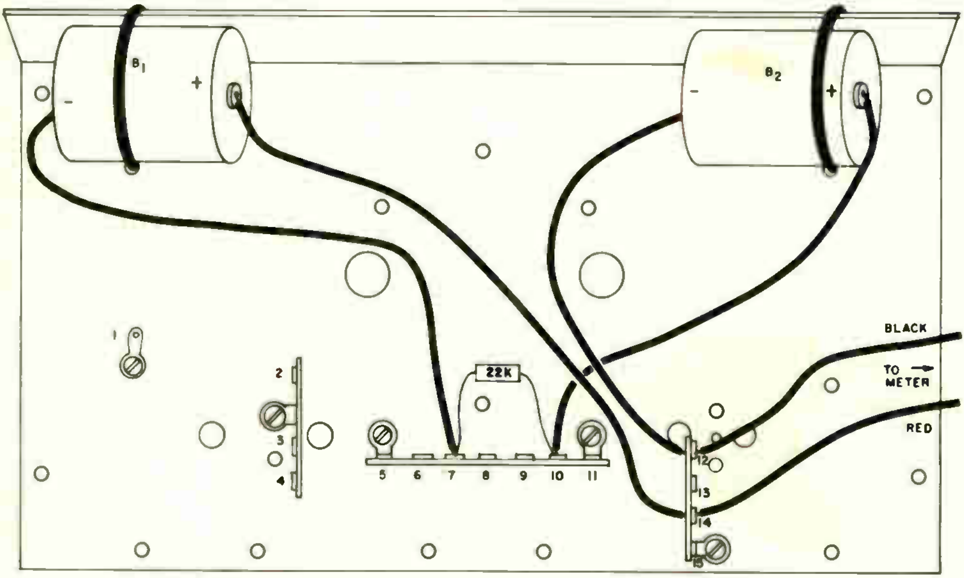


Fig. 7-5. Chassis wired for Step 3.

Notice that the readings are the same in all three steps. This demonstrates an extremely important fact. The value of the current is the same throughout the entire circuit. This means you can connect a meter at any point in a simple series circuit to measure the current; the reading will be the same regardless of where the meter is connected.

It is easy to see why the current in a series circuit is the same throughout the entire circuit. When you close the circuit by touching the battery wire to the circuit, electrons begin to leave the negative terminal of the battery. They strike other electrons and cause them to move. These electrons, in turn, strike additional electrons, and so on throughout the entire circuit. This, of course, occurs instantaneously; as soon as the circuit is completed, electrons start moving through the entire circuit.

At the same instant that electrons begin to leave the negative terminal of the battery, pushing other electrons before them, other electrons begin entering the positive terminal of the battery, because the electrons are attracted by the positive potential. The number of electrons moving in one part of the series circuit is exactly equal to the number of electrons moving in any other part of the series circuit.

Instructions for Statement No. 7: In the preceding experiment, you demonstrated that when resistors are connected in parallel, the total resistance of the combination is lowered. If the applied voltage does not change, this results in an increase in current. For this Report Statement, you will connect a low resistance in series with a high resistance. Then you will shunt each resistance with an 82,000-ohm resistor and note the effect on the total circuit current.

7

4

To carry out the experiment for this statement, you will need one 100,000-ohm resistor and one 82,000-ohm resistor. Wire the circuit as shown in Fig. 7-6. Connect a 100,000-ohm resistor from terminal 10 to terminal 13. Solder both connections. Check your circuit to see that it is wired according to Fig. 7-6. Solder the positive battery wire to terminal 13.

Note the reading on the meter on the 30-volt scale. Bend the leads of the 82,000-ohm resistor so that you can conveniently bridge the resistor across either the 100,000-ohm or the 22,000-ohm resistor. Bridge the 82,000-ohm resistor first across the 100,000-ohm resistor and note the meter reading on the margin. Next move the 82,000-ohm resistor over and bridge the 22,000-ohm resistor. Again, read the meter and note the reading in the margin.

Compare the two meter readings and answer the Report Statement.

Unsolder the positive battery lead from terminal 13. Unsolder and remove the 100,000-ohm resistor connected between terminals 10 and 13 and the 22,000-ohm resistor connected between terminals 7 and 10. Unsolder and remove the short red wire between the positive terminal of B_1 and terminal 14. Unsolder the red wire from terminal 12. (The other end of

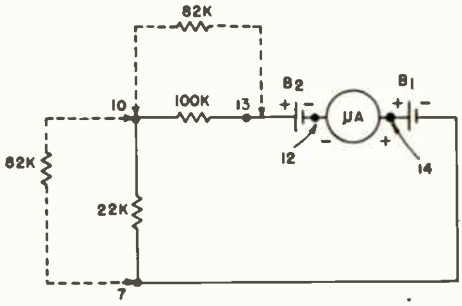


Fig. 7-6. Circuit for Statement 7.

this wire is soldered to the negative terminal of B_2.) Solder the free end of this wire to the positive terminal of B_1 to connect the two cells in series again. Clean and straighten the leads of the resistors you removed and clean all unused terminals.

Statement No. 7: When I shunted the 100K-ohm resistor with an 82K-ohm resistor, and then shunted the 22K-ohm resistor with the 82K-ohm resistor, I found that the effect on the current was:

(1) greater when the 22K-ohm resistor was shunted.
[✓ *(2) greater when the 100K-ohm resistor was shunted.*]
(3) the same in both cases.

EXPERIMENT 8

Purpose: To show that the total current flowing in a parallel circuit is the sum of the currents flowing in the branches.

Introductory Discussion: In any piece of electronic equipment, there are usually several tubes or transistors connected across a single power supply. Each circuit, or stage, as they are usually called, generally draws a different current. The total current that the power supply must provide is equal to the sum of the currents drawn by the individual stages. Each stage acts as a separate load connected across the power supply. If a defect develops in one stage so that the stage draws more current than it should, not only will that stage be overloaded, but also the total current that the power supply must furnish will increase. As a result, the power supply may be overloaded. It is important for you to remember this when you start doing repair work. If a power transformer overheats, it does not necessarily indicate that the transformer is defective; it often indicates

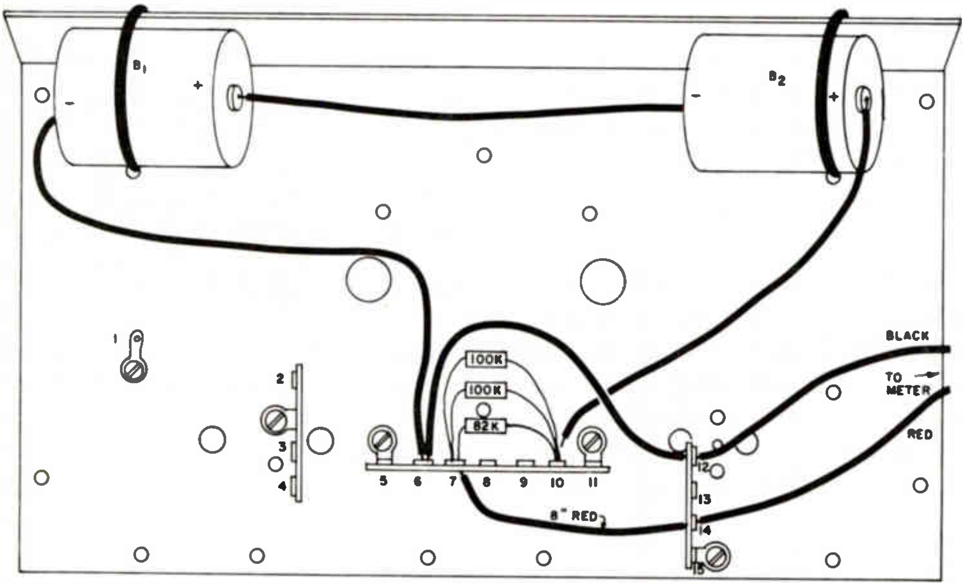


Fig. 8-1. Chassis for Step 1.

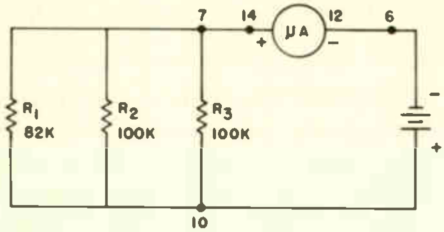


Fig. 8-2. Schematic of circuit for Step 1.

that a defect in some stage other than the power supply is causing the transformer to overheat.

In this experiment you will prove that the sum of the individual branch currents in a parallel circuit is equal to the total circuit current.

Experimental Procedure: In addition to the parts already on the experimental chassis you will need the following parts:

2 **100K-ohm resistors**
1 **82K-ohm resistor**
Hookup wire

1 9
4' 2/8

You should have the two flashlight cells connected to form a 3-volt battery on your chassis. For this experiment, you must wire your circuit as shown in Figs. 8-1 and 8-2.

Solder the two 100,000-ohm resistors and the 82,000-ohm resistor to terminals 10 and 7. You should then have two 100,000-ohm resistors and the 82,000-ohm resistor connected in parallel. Connect the black wire from the negative terminal of B_1 to terminal 6. Next strip 1/4" of insulation from each end of a 5" length of black hookup wire and solder this wire to terminals 6 and 12 as indicated in Fig. 8-1.

Remove about 1/4" of insulation from each end of an 8" length of red hookup wire. Solder one end to terminal 14 and solder the other end to terminal 7. Do not connect the positive battery lead at this time.

Before you go to Step 1, carefully check your work with the schematic of Fig. 8-2 and the pictorial drawing of Fig. 8-1. Make sure you have made all of the connections correctly.

Step 1: To measure the total current flow in a parallel circuit.

Touch the positive battery lead (connected to the positive terminal of B_2) to terminal 10. Observe the readings on the 30-volt scale on your meter. Remove the positive battery lead from terminal 10 after recording your reading in the space provided for Step 1 in Fig. 8-3.

STEP	READING
1	14.9
2	4.9
3	4.9
4	6

Fig. 8-3. Record your reading for Experiment 8 here.

With the arrangement shown in Fig. 8-2, the three resistors are in parallel and the current which you measured is the total current flowing in the circuit.

Step 2: To measure the current through a 100,000-ohm resistor.

You will use the circuit shown in the schematic diagram in Fig. 8-4. To change your wiring to make this circuit, unsolder the lead of the 82,000-ohm resistor and the lead of one 100,000-ohm resistor from terminal 7. Solder these two leads to terminal 6.

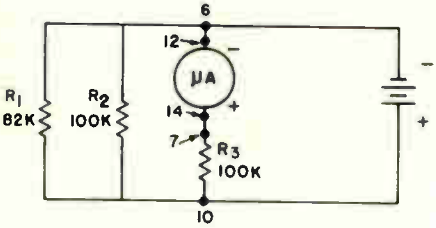


Fig. 8-4. Circuit for Step 2.

As you can see in the schematic, when the circuit is completed, current will flow through all three resistors. However, only the current through R_3 the 100,000-ohm resistor connected to terminal 7 will flow through the meter.

Touch the positive battery lead to terminal 10. Read the meter on the 30-volt scale and record your reading for Step 2 in Fig. 8-3.

Step 3: To measure the current through the second 100,000-ohm resistor, R_2.

Fig. 8-5 shows the circuit. To make the necessary changes, unsolder the 100,000-ohm resistor lead from terminal 7 and resolder it to terminal 6. Then unsolder the lead of the other 100,000-ohm resistor from terminal 6 and resolder it to terminal 7.

Touch the positive battery lead to terminal 10 and observe the meter indication on the 30-volt scale. Remove the battery lead from terminal 10 after recording your reading in the space for Step 3 in Fig. 8-3.

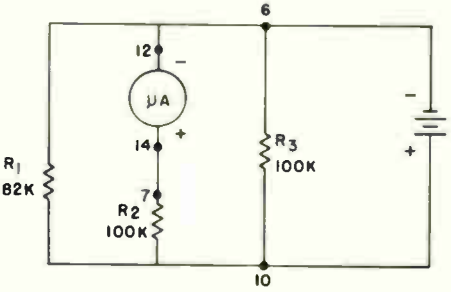


Fig. 8-5. Circuit for Step 3.

Step 4: To measure the current through the 82,000-ohm resistor.

Modify the circuit as shown in the schematic in Fig. 8-6. Unsolder the 100,000-ohm resistor lead from terminal 7 and resolder it to terminal 6. Unsolder the lead of the 82,000-ohm resistor from terminal 6 and resolder it to terminal 7. This places the meter in the 82,000-ohm resistor circuit only.

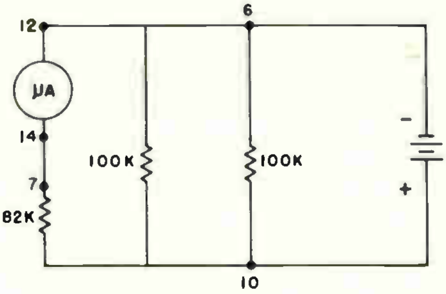


Fig. 8-6. Circuit for measuring the current through the 82K-ohm resistor.

Touch the positive battery lead to terminal 10. Read the meter on the 30-volt scale. Remove the positive battery lead from terminal 10 after recording your reading in the space provided for Step 4 in Fig. 8-3.

Discussion: In this experiment, you have measured the total current flowing in a circuit, and also the current flowing in the individual branch circuits. Since you used two 100,000-ohm resistors, you should have found that the current flowing through these resistors was the same.

In other words, the readings you obtained in Steps 2 and 3 should have been equal.

In actually taking this measurement, you may have found a slight variation because the resistors have a tolerance of 10%. Even though we call the resistor a 100K-ohm resistor, its actual resistance may be as much as 10,000 ohms more or less than 100,000 ohms. The resistance in series with the meter, therefore, may be any value between 90,000 and 110,000 ohms, which would account for the variation in your measurements. The 82,000-ohm resistor can have any value between 73,800 ohms and 90,200 ohms. Therefore, it is actually possible to have little or no difference in reading between the 82,000-ohm resistor and one or both of the 100,000-ohm resistors. In most electronics work, resistor values are not critical, and it is much more economical to use a resistor having a 10% tolerance, than it is to use a resistor having a 1% tolerance.

To show that the total current flowing in the circuit is equal to that in the individual branch circuits, add your readings for Steps 2, 3, and 4, and compare the result with the readings for Step 1. The sum of the readings recorded in Steps 2, 3, and 4 should be approximately equal to the reading you have recorded in Step 1.

Instructions for Statement No. 8: For this Statement, you do not need to take any additional measurements. You can use the readings you took in the experiment to answer the statement.

Answer the statement and unsolder and remove the two 100,000-ohm resistors and the 82,000-ohm resistor from terminals 6, 7, and 10. Remove the red wire from terminals 7 and 14 and remove the black wire from terminals 6 and 12.

Statement No. 8: When I measured the individual branch currents flowing in the circuit consisting of two 100K-ohm resistors and one 82K-ohm resistor, I found that the current was greatest

(1) through one of the 100K-ohm resistors.
[✓ *(2) through the 82K-ohm resistor.*]

This shows that maximum current will flow through the branch in the parallel circuit having

[✓ *(1) the lowest resistance.*]
(2) the highest resistance.

EXPERIMENT 9

Purpose: To show that a microammeter can be used as a voltmeter if a suitable resistor is placed in series with the meter.

Introductory Discussion: You have seen how a microammeter can be used to indicate the presence of current and to show if the current increases, decreases, or remains constant when circuit conditions are changed. We have not been able to measure the current in microamperes or milliamperes because the meter is not calibrated to read in microamperes. It would be possible to calculate the current from your scale readings, but since we are not interested in exact values, it is not necessary.

Your meter is a 0-200 microammeter. This means that a current of 200 microamperes must flow through the meter to give a full-scale deflection. In other words, when the pointer is at 30 on the 30-volt scale, the current flowing through the meter is 200 microamperes. (Microamperes is abbreviated μa.)

If your meter had a 200 microampere (200 μa) scale printed on it, and we inserted a resistance in series with the meter, and then connected the combination across a voltage source, you could read the current through the meter. The current would depend upon two things: the voltage of the source, and the resistance we placed in series with the meter. If we knew what the resistance was, we could read the current from the meter, and then calculate the voltage by using Ohm's Law. Ohm's Law states that $E = I \times R$. So we would multiply the current in amperes by the resistance in ohms to get the voltage of the source.

This arrangement has one drawback, however. It takes quite a bit of time to make the mathematical calculations. Actually, it is not necessary to do this, because as long as the resistance remains unchanged, the current will depend only on the voltage. Therefore, we can calibrate the meter to read directly in voltage. Now let us see how we can find out what resistor we need in order to use the 3-volt range on the meter.

To do this, we again turn to Ohm's Law. One form of Ohm's Law states that the resistance is equal to the amount of voltage divided by the amount of current. In other words, $R = E \div I$. We want the meter to read full scale when the voltage applied is 3 volts; therefore E will be equal to 3. We know that the meter is a 200 microampere meter; it takes 200 microamperes (200 μa) of current to make the meter read full scale. Converting this value to amperes, we get .0002 ampere. Now, to get the value of resistance needed, we divide 3 by .0002. This will give us 15,000. Therefore, the resistance value that should be added to the circuit is 15,000 ohms.

If we want to build an accurate meter, we will have to subtract the resistance of the meter itself from the resistance to be placed in series with the meter. However, the resistance of your microammeter is small compared to 15,000 ohms, so we will simply connect the 15,000-ohm resistor in series with the meter to give us a voltmeter that will read 3 volts on full scale. The error introduced by disregarding the meter resistance will be unimportant in this experiment.

As mentioned earlier, the scales on the meter are labeled 0 to 12 and 0 to 30. For the 3-volt scale, read the 0 to 30 volt scale but mentally divide the reading by 10, or place a decimal point before the last digit. For example, for a full scale reading, the pointer will point to 30. Dividing this by 10 gives us 3.0. Similarly, a reading of 20 is actually 2.0 on the 3-volt scale, just as 15 is 1.5 volts, 5 is 0.5 volts and so on.

Experimental Procedure: In this experiment, in addition to your meter and chassis with parts mounted, you will need the following parts:

1 15,000-ohm resistor
Hookup wire

Prepare 1′ lengths of red and black hookup wire. Remove about 1/2″ of insulation from each end of the wires.

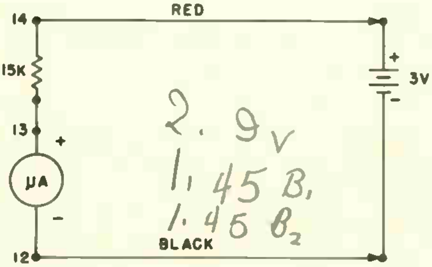
Step 1: To convert your microammeter to a voltmeter.

Unsolder the red meter lead from terminal 14 and reconnect to terminal 13. Connect the 15,000-ohm resistor from terminal 13 to terminal 14. Solder terminal 13. Solder one end of the 1′ length of red wire to terminal 14. Leave the other end free.

Solder one end of the 1′ length of black hookup wire to terminal 12. The meter can now be used as a 0 to 3 volt voltmeter. The black wire connected to terminal 12 is your *negative voltmeter lead* and the red wire connected to terminal 14 is your *positive voltmeter lead.*

Step 2: To measure the voltage of the two flashlight cells connected in series.

The cells should still be connected in series as they were in the last experiment. Touch the negative meter lead (the black wire connected to terminal 12) to the negative terminal of the 3-volt battery, and touch the positive meter lead to the positive terminal of the 3-volt battery. Fig. 9-1 shows the circuit used in this step. Note the reading on the 3-volt scale on your meter. The reading should be approximately full scale, indicating a voltage of about 3 volts. The reading might be a little higher or lower than full scale, depending upon the tolerance of the 15,000-ohm resistor and the actual voltage of your battery. In general, new flashlight cells have a terminal voltage of 1.55 volts which drops to about 1.5 volts when the cells are heavily loaded (are supplying large current). In this circuit there is hardly any load so the battery voltage should be 2 times 1.55 volts or about 3.1 volts which would make your meter read slightly above full scale.



2.9v
1,45 B_1
1.46 B_2

Fig. 9-1. Circuit to measure battery voltage.

Step 3: To measure the voltage of a single flashlight cell.

Touch the positive voltmeter lead to the positive terminal of one cell, and touch the negative meter lead to the negative terminal of the same flashlight cell. Note the reading on the meter. The reading should be about center scale, indicating a voltage of approximately 1.5 volts. Check the voltage of the other flashlight cell in the same way.

Discussion: The meter that you constructed in this experiment is often referred to as a 5,000-ohms per volt voltmeter. We usually write this as 5,000 ohms/volt. Notice that to convert the meter to a 3-volt voltmeter, we use a 15,000-ohm resistor. If we wanted to convert the meter to a 12-volt meter, we would have used a 60,000-ohm resistor. If we wanted to convert the meter to a 30-volt meter, we would have used a 150,000-ohm resistor. In all cases, to find the resistance needed, we multiply the required full scale voltage by 5,000.

In the early days of electronics, meters with sensitivities of 1,000 ohms/volt and 5000 ohms/volt were the only types available. Today most meters have sensitivities of 20,000 ohms/volt to 150,000 ohms/volt.

The sensitivity of the meter used in service work is important. If the meter has a sensitivity of only 5,000 ohms per volt, it is quite possible that you will not get an accurate indication of the voltage in a circuit. In the next experiment we will show you exactly how this can happen and why the sensitivity of the meter is important to the serviceman.

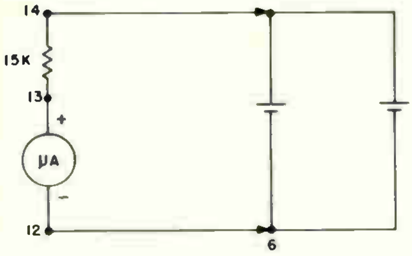


Fig. 9-2. Circuit for Statement 9.

Another type of meter, the vacuum tube voltmeter or the transistor voltmeter, has an even higher sensitivity than the meters previously discussed. For this reason most electronics technicians prefer this type to the simple voltmeter of the type you have just constructed. You will build a sensitive transistor voltmeter in the next Training Kit.

Instructions for Statement No. 9: In this statement, you are to measure the voltage of the two flashlight cells when they are connected in parallel. To do this, unsolder the red wire from the positive terminal of cell B_1 which is on the left side of your chassis. This wire should still be attached to the negative terminal of cell B_2. Solder the free end of this wire to terminal 6. Solder the free end of the positive battery lead (the wire soldered to the positive terminal of B_2) to the positive terminal of B_1. Check your work against Figs. 9-2 and 9-3.

Touch the positive voltmeter lead to the positive terminal of battery B_1 or B_2 and the negative meter lead to terminal 6. Note the reading on your meter, and answer the statement.

Unsolder the red wire from the positive terminal of battery B_1 and push the free end out of the way. Unsolder the red wire from terminal 6 and solder the free end to the positive terminal of flashlight cell B_1. Leave the 15,000-ohm resistor connected to terminals 13 and 14, and the

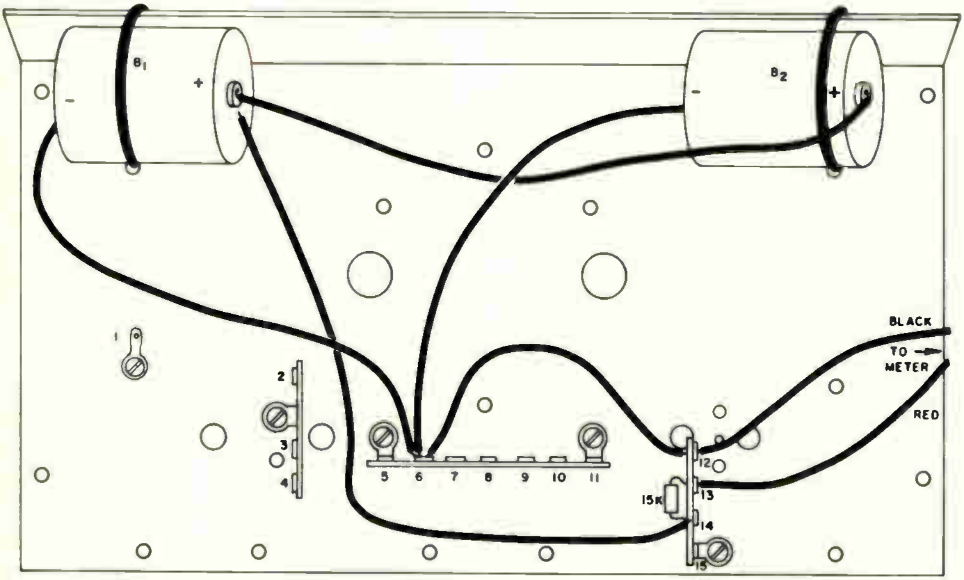


Fig. 9-3. Chassis used for Statement 9.

red and black voltmeter leads connected to terminals 12 and 13.

Statement No. 9: When I measured the voltage of the two parallel-connected flashlight cells, I found that it was approximately

(1) 3 volts.
[✓ *(2) 1.5 volts.*]
(3) 0.

EXPERIMENT 10

Purpose: To show that in a series circuit, there is a voltage across each part, that the sum of the voltages is equal to the source voltage, and that a voltmeter can upset the voltage division.

Introductory Discussion: You already know that if you connect your voltmeter across the battery, you get an indication of the voltage produced by the battery.

When the battery is connected to a series circuit, the battery voltage drives electrons through the circuit. The electrons, in moving through each part of the circuit, set up a voltage across each part. If you accurately measure the voltage across each part and add these voltages, you will find that the sum of these voltages is equal to the source voltage.

In this experiment, you will construct a simple circuit and measure the voltage across each of the individual parts in the circuit to prove that the sum of the voltages is equal to the battery voltage.

Experimental Procedure: In this experiment, in addition to the meter and chassis, you will need:

1 470-ohm resistor
1 680-ohm resistor
1 1,000-ohm resistor
2 100,000-ohm resistors
1 82,000-ohm resistor
2 Flashlight cells

Your flashlight cells should still be connected in series to form a 3-volt battery.

Construct the circuit shown in Fig. 10-1. Solder one lead of a 1,000-ohm resistor to terminal 6. Push the free lead through the slot in terminal 4. Connect the 680-ohm resistor between terminals 3 and 4 and solder terminal 4. Connect the 470-ohm resistor between terminals 2 and 3. Solder terminal 3. Solder the resistor lead and the free end of the positive battery lead to terminal 2.

Step 1: To measure voltages in a low-resistance series circuit.

You will use your 3-volt meter to measure the voltages in the circuit shown in Fig. 10-1.

To measure the source voltage, hold the negative voltmeter lead on terminal 6, and touch the positive meter lead to terminal 2. Observe the meter on the 3-volt scale and place your reading in the space for the source voltage in Fig. 10-2.

Next, while holding the negative voltmeter lead on terminal 6, touch the positive lead to terminal 4 and measure

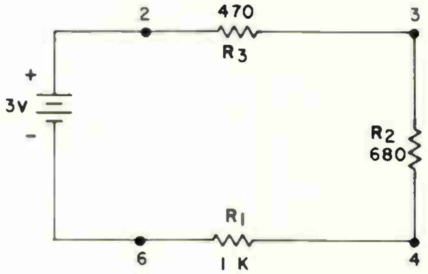


Fig. 10-1. Circuit for Experiment 10.

	READINGS
R_1	1.35
R_2	.85
R_3	.65
$R_1+R_2+R_3$	2.85
SOURCE	2.9

Fig. 10-2. Record your reading for Step 1 here.

the voltage across resistor R_1. Record this voltage in the space provided for R_1 in Fig. 10-2.

Move the positive meter lead to terminal 3 and the negative meter lead to terminal 4 and measure the voltage across resistor R_2. Record your reading in the space provided for R_2 in Fig. 10-2.

To measure the voltage across resistor R_3, touch the positive meter lead to terminal 2 and the negative meter lead to terminal 3. Read the voltage on the 3-volt scale on your meter and record your reading in the space provided for resistor R_3, in Fig. 10-2. Now add together the three voltages you recorded for R_1, R_2, and R_3 and put this value in place labeled $R_1 + R_2 + R_3$ in Fig. 10-2.

Unsolder the positive battery lead from terminal 2, to open the circuit. Unsolder and remove the 470-ohm, the 680-ohm and the 1,000-ohm resistors.

Step 2: To measure voltage in a higher resistance series circuit.

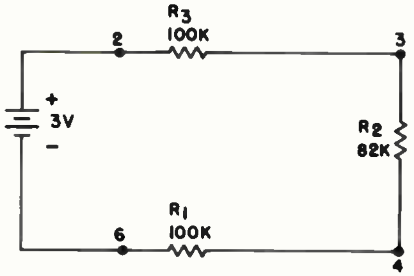


Fig. 10-3. Circuit used in Step 2.

1.35
.85
2.20
.65
2.85

Construct the circuit shown in Fig. 10-3. Solder one lead of a 100,000-ohm resistor, R_1, to terminal 6. Connect the other lead to terminal 4. Connect one lead of the 82,000-ohm resistor to terminal 4 and solder. Connect the other lead of this resistor to terminal 3. Connect and solder the other 100,000-ohm resistor, R_3, from terminal 3 to terminal 2. To complete the circuit, solder the positive battery lead to terminal 2.

Measure the voltage applied to the circuit by holding the positive voltmeter lead on terminal 2 and touching the negative voltmeter lead to terminal 6. Read your meter on the 3-volt scale and record your reading in the space reserved for the source voltage in Fig. 10-4.

	READINGS
R_1	.25
R_2	.2
R_3	.25
$R_1+R_2+R_3$	.75
SOURCE	2.9

Fig. 10-4. Record your readings for Step 2 here.

Using the same technique you used in Step 1, measure the voltages across each of the three resistors. Record these voltages in the spaces provided for it in Fig. 10-4. Now add together the three voltages you recorded for R_1, R_2, and R_3 and put this value in the place labeled $R_1 + R_2 + R_3$ in Fig. 10-4.

When you have made your readings, disconnect the positive battery lead from terminal 2.

Discussion: In Step 1, you measured the source voltage applied to the circuit and you measured the voltage across each resistor. You found that the source voltage was about 3 volts. This is the voltage across the three series-connected resistors.

The voltage drop across R_1 was about 1.4 volts, across R_2 it was about .95 volts and across R_3 about .7 volts. When you added the voltage drops across resistors R_1, R_2 and R_3, you should have found the sum to be approximately equal to the source voltage.

The voltage across a resistor is determined by the current in the resistor and the value or resistance of the resistor. As you would expect from Ohm's Law, the largest resistor has the largest voltage across it while the smallest resistor has the smallest voltage.

Another important point that you should learn from the experiment is how to connect the voltmeter to measure voltage. A voltmeter is always placed in parallel with or across the voltage you are interested in measuring.

To measure the battery voltage in the circuit in Fig. 10-1, you measure between terminals 2 and 6, which are directly across the battery. To measure the voltage across resistor R_1, you measure the voltage between terminals 4 and 6. In every case, the positive meter lead is connected to a more positive point than is the negative meter lead. The negative battery terminal is the most negative point in the circuit. In Fig. 10-1, the voltage at terminal 4 is more positive than the voltage at terminal 6. Similarly, the voltage at terminal 3 is more positive than the voltage at terminal 4 and the voltage at terminal 2 is more positive than the voltage at terminal 3.

You must always connect your voltmeter so the positive lead is connected to the more positive terminal. Otherwise, your meter will read backwards and may be damaged.

In Step 2, you also found that the supply voltage is about 3 volts. However, when you add the three readings taken for Step 2, you will find that the three voltage drops do not add up to 3 volts. At first glance, you might think that something is wrong.

Actually, the error is due to your meter resistance. The circuit you have when you connect the meter across R_1 is shown in Fig. 10-5.

Since the resistance of the voltmeter, which consists of the 15,000-ohm resistor and the resistance of the 0 to 200 microammeter, is only slightly more than

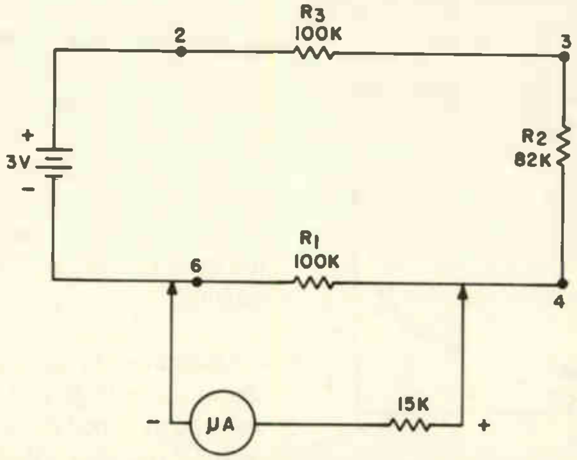


Fig. 10-5. Circuit for Experiment 10 with meter connected across R_1.

15,000 ohms, the total resistance of R_1 and the meter in parallel with it is much less than the 100,000-ohm value of R_1 alone. The resistance of the combination is very close to 15,000 ohms. Therefore, most of the voltage will be dropped across resistor R_2 and R_3, and very little will appear across the combination of R_1 and the meter circuit in parallel with it.

The same thing is true when you connect your meter across R_2 and R_3. Each time you connect the meter across a high resistance, the parallel combination of the meter and the resistor across which you are measuring voltage forms a resistance that is much lower than the original resistor value. The entire circuit, therefore, is upset and the voltage you measure is not the true voltage that is across the resistor when the meter is not connected to it.

To prevent such erroneous readings, you need a meter with a very high resistance. If your meter had a sensitivity of 100,000 ohms per volt on the 3-volt scale, you would have a total resistance of 300,000 ohms in the voltmeter circuit. Then, when you make your measurements, you would be placing 300,000 ohms in parallel with 100,000 ohms. Although the meter resistance is still low enough to upset the circuit you used in this experiment, it would not upset the circuit nearly as much as the 15,000-ohm resistance did.

The resistor values used in the first step were much less than the combined value of the meter and its series resistor. For this reason, the meter resistance has very little effect on the readings you made in the circuit in Step 1.

In your next set of experiments, you will build a transistorized voltmeter. This meter has a resistance of several megohms. Thus, when you use this meter to measure the voltage in high resistance circuits, you will get a more accurate voltage indication than you would using a simple voltmeter such as that which you used in this experiment.

Instructions for Statement 10: For this statement, you are to measure the voltage drop across two resistors. R_1 and R_2 in Fig. 10-3. Solder the positive battery lead to terminal 2. Touch your negative meter lead to terminal 6 and the positive meter lead to terminal 3. Observe your meter indication on the 3-volt scale and write the reading in the margin on this page. .4

Statement No. 10: When I measured the voltage across resistors R_1 and R_2, I found that the voltage was

[✓ *(1) less than 1 volt.*]
(2) approximately 1.5 volts.
(3) approximately 3 volts.

After you have answered the statement, unsolder the positive battery lead from terminal 2 and push it out of the way. Unsolder and remove the red and black meter leads and all other parts and wires connected to terminals 12, 13, and 14. Straighten and clean the leads of the 15,000-ohm resistor and set it aside.

You should still have the two flashlight cells connected in series and attached to the chassis. You should also have the two 100K-ohm and one 82K-ohm resistors soldered to terminals 2, 3, 4 and 6. These resistors and the 3 volt battery will be used in the first experiment of the next training kit.

Looking Ahead

This completes the experiments in Kit 1T. One of the most important things you should have learned is how to solder correctly. As we pointed out, you will make soldered connections in all your electronics work, and one poorly soldered connection can cause you hours of unnecessary work.

In later kits you will have further experience in reading the meter. Of course, you will use the meter throughout your Practical Demonstration Course. You should have learned how to read the 0 to 30 volt and 0 to 12 volt scales in this group of experiments; in the next kit, you will learn how to read the ohmmeter scale. You also demonstrated a number of important basic circuit actions. It is much easier to study and understand the more advanced circuits that you will encounter later if you understand how the simple circuits work, and what changes in the circuit will do to voltage distribution and current flowing in the circuit.

In the next kit, you will build a transistorized voltmeter (tvom). You will find this work extremely interesting, and at the same time you will be building an instrument that will be useful to you in the rest of your experiments, and later when you start work in any branch of the electronics field. In addition to building the tvom you will continue with your studies of basic circuits.

Check to see that your training Kit Report sheet is completed and send it to NRI for grading.

While waiting for the return of this Report and for your next kit, prepare the parts you have left over for use in later kits. The parts left over are shown in Table I. *Remove the meter from its box and unsolder and remove the diodes and wires from the meter terminals.* Also, remove the solder lugs. Clean the meter terminals, and place the meter back in its box. Since the meter is a delicate instrument, be sure to put it in a safe place.

TABLE I

1	Pot mtg. bracket	2	4700-ohm resistors
1	Chassis plate	1	6800-ohm resistor
1	Etched circuit board with tube socket	1	15,000-ohm resistor
1	Marking crayon	1	22,000-ohm resistor
1	Meter	1	1/4" X 6-32 machine screw
1	6-32 hex nut	2	1/4" X 4-40 machine screws
2	4-40 hex nuts	2	Large solder lugs
1	1000-ohm potentiometer	2	Silicon diodes
1	470-ohm resistor		Hookup wire
1	680-phm resistor		Solder
3	1000-ohm resistors		

IMPORTANT: Be sure to save ALL PARTS from this Kit, including screws and nuts, because you will need them later. Keep small parts in individual envelopes or boxes.

The following parts are attached to the chassis plate:

2	Flashlight cells
1	3-lug terminal strip
1	4-lug terminal strip
1	7-lug terminal strip
1	Small solder lug
5	1/4" × 6-32 machine screws
5	6-32 hex nuts
2	100,000-ohm resistors
1	82,000-ohm resistor

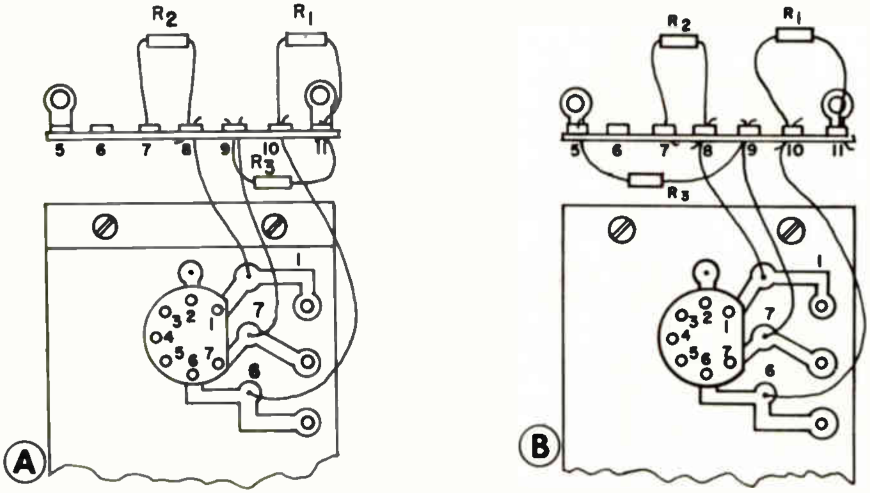


Fig. 4-6. Examples of how you could have wired the circuit used in Experiment 4.

Important Notice

As you use your soldering iron, a scale will accumulate on it. Eventually this scale will keep the iron from heating properly, and you will have to remove it. To do so, remove the tip from the barrel. Remove the scale from the tip and tap the end of the barrel against the workbench to loosen and remove the scale in the barrel. Refile the tip, if necessary, and put it back in the barrel.

If you have a soldering gun, poor contact may develop between the tip and the metal terminals of the gun. This can be eliminated by loosening and then tightening the nuts holding the tip in place. Make sure the nuts are tightened securely. Clean and re-tin the tip when it gets dirty, and replace it when it gets pitted.

Warning

You are expected to make a grade of A, B, C, or D for each group of ten experiments in this Practical Demonstration Course. If any of your reports come back to you marked "Low," you are to repeat the experiments and report statements marked "X" and then send in a complete new set of answers, using the new report blank we will send you. Since this procedure may mean that you will have to dismantle equipment that is to be used as a unit in succeeding experiments, do not begin work on the next Kit until you have received a grade of A, B, C, or D.

Each Day Counts . . .

Each day of our life offers its own reward for work well done, its own chance for happiness. These rewards may seem small, and these chances may seem petty in comparison with the big things we see ahead.

As a result, many of us pass by these daily rewards and daily opportunities, never recognizing that the final goal, the shining prize in the distance, is just a sum of all these little rewards we must win as we go along.

Innovation in learning
by a McGraw-Hill
Continuing Education School

ACHIEVEMENT THROUGH ELECTRONICS

nri

TRAINING KIT MANUAL

1T

NATIONAL RADIO INSTITUTE • WASHINGTON, D. C.

TRAINING KIT MANUAL 1T

PRACTICAL DEMONSTRATIONS
IN BASIC ELECTRONICS

A Plan For Studying The Experiments

As you know, these Experimental Kits are intended to come to you on a definite schedule. This arrangement is so that you will study the necessary theory in your regular lessons before you carry out any corresponding experiments. This permits you to adopt either of the following plans of study:

1. You may wish to complete one or two experiments in a kit, do a lesson, and then return to the kit for one or two more experiments. This plan permits the experiments in one kit to be finished about the time the next kit is due. Thus, the lessons and experiments run along together, and provide you with a varied program of study.
2. You may prefer to break away from your lessons and to complete all the experiments in a kit at one time before going back to your lessons. This plan has the advantage that you do not waste any time getting out and putting away materials, but it can be followed only if you can leave your equipment set up long enough to finish.

Whichever plan you follow, you can begin NOW with the experiments in this kit. However, be sure to read the preliminary information on pages one through sixteen before you begin, so you will know just how the experiments are to be carried out. In a similar manner, begin on future kits as soon as you receive them.

NOTICE

NRI has set up the CONAR Division of the National Radio Institute to handle the sale of professional test equipment and other electronic equipment. NRI has had unsurpassed experience in the design of quality kits. All CONAR kits are designed and produced by the National Radio Institute. The transistorized volt-ohmmeter you will build as part of your training is the CONAR Model 212. This is the same professional tvom you will see advertised nationwide. Several of the parts you received in this kit, including the meter, will be used in the assembly of your tvom.

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INSTRUCTIONS FOR PERFORMING EXPERIMENTS 1 THROUGH 10

LECTURE-ROOM DEMONSTRATIONS YOU PERFORM IN YOUR OWN HOME

How many times have you heard the expression, "Seeing is believing"? Probably many times, because it is human nature to doubt something you cannot see or touch.

Although you can learn how a piece of equipment works from pictures and words, the average person understands better if he can actually set up equipment and make tests himself to see how it works.

You must have a knowledge of theory before you can work successfully in the radio-TV-electronics field. However, unless you know how to apply theory and make tests, your knowledge is useless. Theory and practical application must go hand-in-hand.

The NRI Course of training is a well-balanced combination of theory and practical instruction. Practical demonstrations and experiments are given in this manual and the following manuals.

Doing these experiments will give you actual experience in handling parts and making measurements, and will help you understand explanations of more advanced circuit actions. This type of experience is more valuable to you than class or lecture-room demonstrations by an instructor in which you take no active part, and you can do the experiments at your own convenience.

This practical work with experimental equipment will help you develop confidence in your own ability and will provide what you need to become a practical technician.

The experiments will help you to solve technical problems you will encounter in your work. You will see for yourself what happens when a particular part is defective, and you will learn how to detect and correct errors and how to adjust circuits.

Every experiment in every manual is important, because it is an actual working demonstration. Do not pass over any of them hurriedly, even though you may feel that you already know the results.

If you look underneath the chassis of any modern piece of electronic equipment, you will see that the connections are soldered. A soldered connection is the most reliable type of connection to make in commercial production because it will not deteriorate much during the entire life of the electronic equipment.

When you repair defective equipment, you must be able to find the defective stage and then the defective part. However, the ability to find what is wrong is of little use unless you also know how to take out the defective part and how to solder the connections for a new part. Furthermore, you may often have to unsolder one or more connections during your tests in order to find the defective part.

In the first section of this manual, you will study the fundamentals of soldering and learn how to make a good soldered connection using actual electronic parts. You will make these connections in ex-

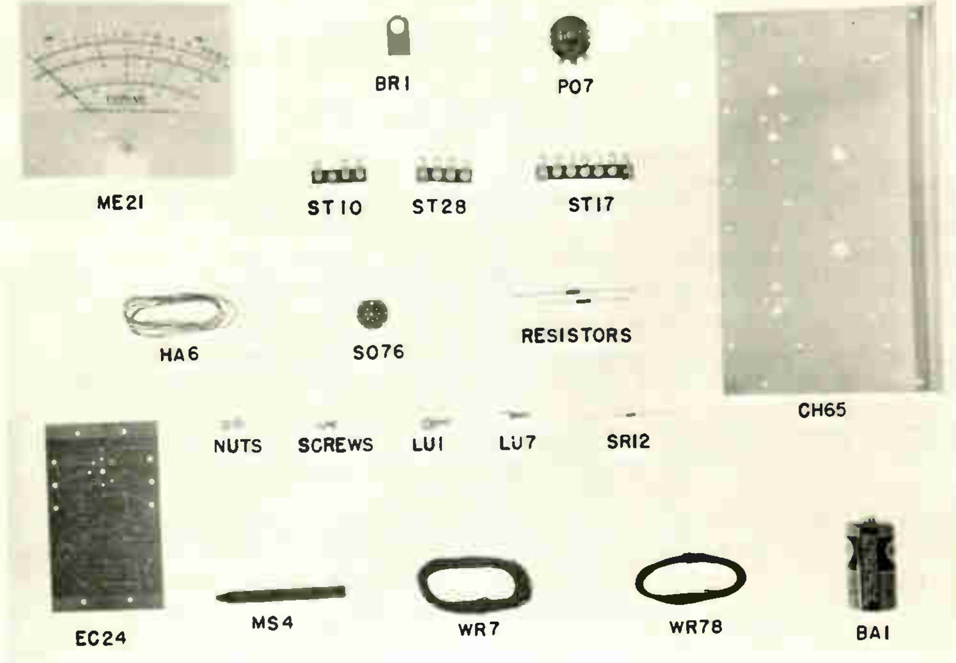

Fig. 1. Parts used in this Experimental Manual are shown here and listed below.

Quan.	Part No.	Description	Price Each
2	BA1	Size D flashlight cell	.20
1	BR1	Pot mounting bracket	.05
1	CH65	Chassis plate	.93
1	EC24	Etched circuit board	1.10
1	HA6	Solder	.41
1	LU1	Solder lug, small	12/.15
2	LU7	Solder lug, large	12/.15
1	ME21	Meter	10.92
1	MS4	Marking crayon	.05
6	NU1	6-32 hex nut	12/.15
2	NU5	4-40 hex nut	12/.15
1	PO7	1000-ohm pot w/lockwasher/nut	.75
1	RE28*	470-ohm resistor	.15
2	RE29	4700-ohm resistor	.15
3	RE30	1000-ohm resistor	.15
2	RE33	22,000-ohm resistor	.15
2	RE36	100,000-ohm resistor	.15
1	RE50	6800-ohm resistor	.15
1	RE52	82,000-ohm resistor	.15
2	RE56	680-ohm resistor	.15
1	RE165	15,000-ohm, 5% resistor	.24
6	SC1	1/4" X 6-32 machine screw	12/.15
2	SC6	1/4" X 4-40 machine screw	12/.15
1	SO76	7-pin tube socket	.12
2	SR12	Silicon diode	.67
1	ST10	3-lug terminal strip	.05
1	ST17	7-lug terminal strip	.12
1	ST28	4-lug terminal strip	.10
1	WR7	25' red hookup wire	.50
1	WR78	6' black hookup wire	.12

*All resistors are 1/2-watt, 10% tolerance unless otherwise specified.

actly the same way that you would in working on commercial equipment. The solder, hookup wire, and other parts that are included in this kit are standard items, just like those that you might use in working on any piece of electronic equipment. In later experiments, you will have practice in working from schematic diagrams. You will also assemble a number of simple circuits to demonstrate some basic electrical laws.

HOW THE MANUALS ARE ARRANGED

The manual for each kit in your Practical Demonstration Course contains the instructions for performing ten experiments. These experiments are numbered consecutively throughout the whole series; Experiments 1-10 are in the first manual, 11-20 in the second, etc. At the end of each experiment is a Statement that you are to complete, so that you can check your work as you go along. When the ten statements have been answered, be sure to submit the training Kit Report to NRI for grading.

In each manual, the figures are numbered to correspond to each experiment. Each figure number has two parts. The first part is the number of the experiment in which it appears, and the second part is the number of the figure within the experiment. For example, Fig. 1-3 would be the third figure in Experiment 1; Fig. 6-2 would be the second figure in Experiment 6. If there are any figures that do not apply to one particular experiment, they will be numbered consecutively in each manual, starting with Fig. 1.

CONTENTS OF THIS KIT

The parts included in your first kit are pictured in Fig. 1 and listed below. Each part that you receive in your kits is assigned a part number. The part number and description appears below Fig. 1. When you need a part for the experiments, you will be given the part value, a description, and in some cases the part number.

Now check the parts that you receive against this list to make certain that you have all of the parts. *Do not lose or discard any of these parts because you will use many of them again in later experiments.*

For your convenience, most of the parts are packed on cardboard under a clear plastic film. This protects the parts during shipment and also makes it easy to inventory your parts. To remove the parts, cut around them with a sharp knife or a razor blade.

IMPORTANT: If any part of this kit is obviously defective or has been damaged during shipment, please return the defective part to NRI for replacement, following the procedure given on the "Packing and Returned Material Slip" enclosed in this kit.

Preparing For The Experiments

Before you start the experiments, there are several things you will need to do. You will need a place to work and tools to work with.

You do not need an elaborate workbench. A folding card table set up near an electrical outlet will be satisfactory. Do not use a metal-top table, because it could cause short circuits that might damage the equipment. If you have to use a metal-top table, cover the top with a nonconductor, such as cardboard or linoleum.

TOOLS YOU WILL NEED

The tools you need to do these experiments are the same as those you will use in all kinds of electronic work. They are pictured in Fig. 2, and listed under the figure. None of these tools are supplied with this kit. Probably you already have some of these tools, since the average home usually does have a few tools for simple repair work.

You can get those tools you do not have from hardware stores, radio-supply

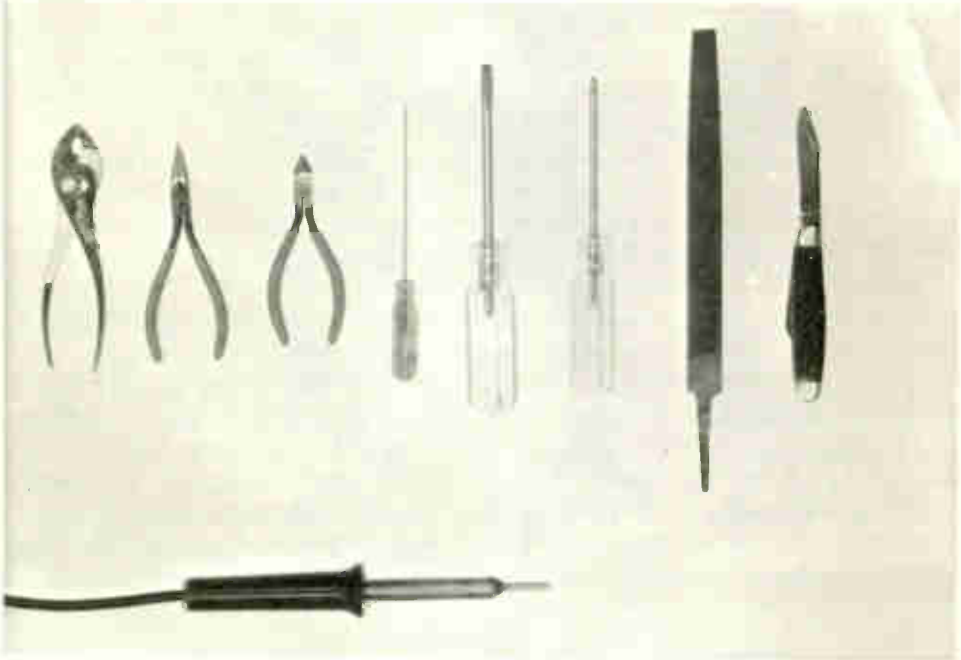

Fig. 2. These are the tools you will need to do these experiments. You probably already have many of them. Get the best ones you can afford; you will be using them throughout your course as well as when you do service work. These tools are not supplied with your kits. From left to right, all-purpose pliers, longnose pliers, diagonal cutters, small screwdriver, medium size screwdriver, Phillips screwdriver, metal-cutting file, and pocket knife. Below the tools is a soldering iron.

houses, or mail-order firms. Since you will use the tools in all of your electronic work, they are a worthwhile investment. Select good quality tools that "feel right" in your hand.

Pliers. The technician needs three types of pliers: longnose pliers, diagonal cutters, and ordinary slip-joint pliers. Each type has its own purpose and should be used for that purpose only. Pliers are designed primarily for holding, bending, and cutting. Many people use them for other purposes so they often ruin them or mar the material on which they are working.

Perhaps the pliers most often used in electronics are the longnose type. Although you may use longnose pliers to hold a nut in position so that it can be started on a screw, you should never use them to tighten nuts. You may spring the jaws so the points will not meet or you could actually break one of the jaws. Use your longnose pliers to hold wires in position for soldering, to remove wires, or for hard-to-reach places.

Diagonal cutting pliers, or "side cutters" as they are often called, are used for most cutting operations. Because the cutting jaws are at an angle, these pliers are ideal for cutting wires close to terminals.

Combination slip-joint pliers, often called "combination pliers," are also in common use. Because of the slip joint, the jaws can be opened wider at the hinge pin so that larger diameters can be gripped. These pliers come in 5, 6, 8, and 10-inch sizes. The thin-type, 6-inch size is best for electronics work.

Screwdrivers. Practically everyone is familiar with the standard screwdriver. The screwdriver is intended for one principal purpose - to loosen or tighten screws. Because the average person uses a screwdriver as a can opener, a pry or pinch bar, and even as a chisel, the screwdriver is one of the most abused tools.

The technician needs three screwdrivers - one with a small blade for loosening setscrews in dial and control knobs and one with a medium blade for general purpose work. He also needs a Phillips screwdriver because screws with a special head known as a "Phillips head" are often used in electronic equipment. Screwdrivers with plastic handles are best because the plastic is a good insulator. Later on you will need a special type of screwdriver, known as an "alignment tool." This is a non-metallic tool for special uses, but you won't need it now.

Files. There are more than twenty types of files. Each type comes in sizes from three to eighteen inches. They may be either single or double cut and are classified according to the different grades of coarseness or fineness, depending upon the size and spacing of the teeth.

The type most often used in electronics is a 10-inch second-cut mill file. It is used to keep the tip of the soldering iron in good condition by removing small amounts of metal, leaving the filed surface smooth. This type of file is also useful in brightening lugs for easier soldering.

Knife. A good knife is useful when preparing wires for connection to other parts; a sturdy pocket knife is fine.

Soldering Iron. The soldering iron is used more often by servicemen than any other tool. Since you will use it often and it is so important, you should choose it carefully. A number of soldering irons suitable for electronics work are shown in

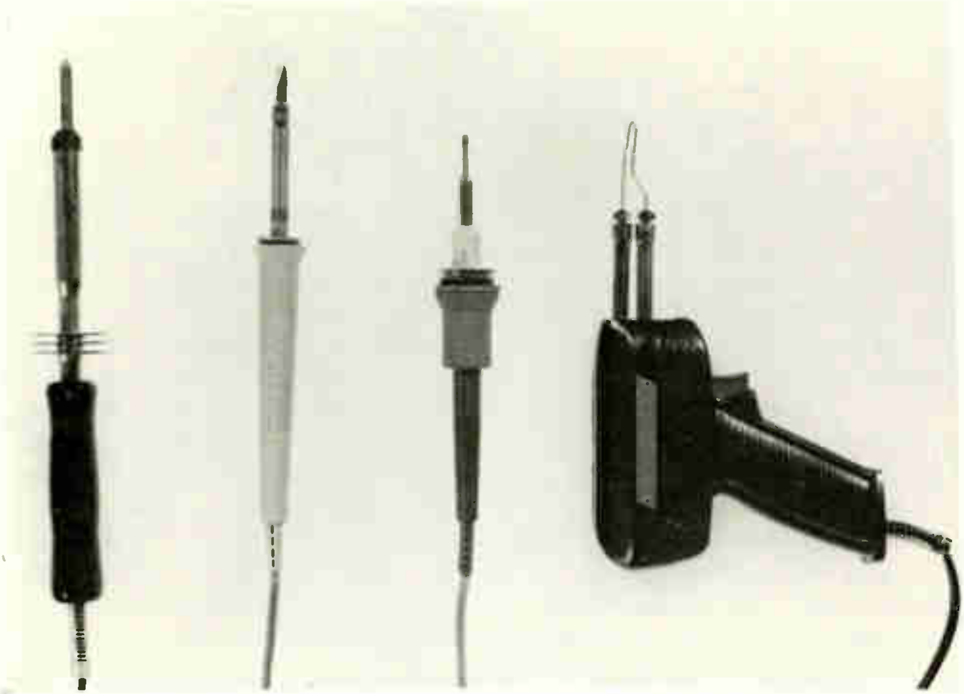

Fig. 3. Several soldering irons suitable for electronics work.

Fig. 3. It is best to buy a soldering iron from a firm that specializes in electronics parts. You should obtain your iron from your local wholesaler, from a mail-order wholesaler, or from the CONAR Instruments Division of NRI.

Hardware stores sometimes carry soldering irons in stock, but they may have only the large type that is used for heavy work, such as automobile radiator repair or roofing work. These irons are too heavy for easy handling and too big to be used where small parts are crowded together.

From left to right in Fig. 3, the first iron is called a medium duty iron. This type of iron generally has a rating of from 50 to 150 watts and is used where a relatively large amount of heat is needed, such as when soldering to the chassis.

The two irons in the center are "pencil" type irons. These types have replaceable heating elements and tips. They are available with various wattage ratings, usually 25 to 40 watts, suitable for general electronic soldering, and 40 to 50 watts, for heavier duty work. These "pencil" irons are the types most suitable for the beginner as they are lightweight and easy to handle. Perhaps the most suitable iron for the beginner would be one like the third iron from the left in Fig. 3. A 37-1/2 element and a chisel-shaped tip make an ideal choice of element and tip.

At the right in the photo is a soldering gun. A gun of this type has the advantage over the iron in that it heats and cools very quickly. Thus, it is excellent for a serviceman making house calls or a technician working on equipment in a plant. He plugs the gun in when he arrives at the job and it is ready for use immediately. Everyone going into electronics, whether on a part-time or full-time basis, will find a gun useful. However, it is not quite as easy to turn out well-soldered connections with a gun as it is with an iron. Therefore, the beginner should start with a conventional soldering iron and learn to use it correctly and later, if he so desires, he can use a soldering gun.

As mentioned previously, the most suitable single iron for general service work and for use in your kits is an electric iron with a tip about an inch long and 1/8" to 1/4" in diameter. The tip should be of the chisel type with two flat surfaces. The wattage rating should not be more than 50 watts, because a high-wattage iron is bulky, and if its barrel touches parts, it may damage them.

When you buy an iron, be sure you get a soldering iron stand with it, to rest the hot iron on when it is not in use. Or get an iron that is designed so that the handle is heavier than the tip end. Then the iron will balance when it is laid down with the tip off the bench.

The average electric soldering iron will operate on ac or dc at 117 volts. Power-line voltages may vary between 110 and 120 volts; an iron designed for 117-volt operation may be used on any voltage between 105 volts and 130 volts.

Although the modern soldering iron is a rugged tool, it should never be abused. Do not use it as a hammer, drop it, or attempt to cool it quickly by plunging it into water. When properly cared for, an iron will last for years.

Although some irons have pre-tinned tips, most tips must be tinned before use. If your iron has a bright, shiny tip or a dull gray tip, it has been pre-tinned, and it is ready for use. If the tip is a natural copper color, you must tin it before using it.

TINNING A SOLDERING IRON

You cannot solder properly unless your soldering iron is properly tinned. Therefore, your first step in learning how to solder is to learn how to tin a soldering iron.

The tip of the soldering iron is made of copper. When an untinned soldering iron is heated, the copper combines with the oxygen in the air, forming a dark coating of copper oxide on the tip of the iron. If you try to use an untinned iron, the copper oxide coating will act as a heat insulator and keep the heat of the iron from the parts you are trying to solder. It will be practically impossible to heat the part sufficiently to melt the solder properly.

You can prevent this by covering the tip of the iron with solder. This is called "tinning" the iron. The solder will form a protective layer over the copper tip so that the oxygen cannot get at the copper and corrode it. The tinned tip will be a good conductor of heat, and you will be able to heat the parts enough to solder them properly.

Preparing the Tip. The first step in tinning a soldering iron is to examine the tip. A photograph of the tip of a new soldering iron that has not been tinned is shown in Fig. 4A, and a photograph of a soldering iron that has been used and needs re-tinning is shown in Fig. 4B. Notice that the tip of the new iron is reasonably smooth, whereas the tip of the iron that has been used is pitted, dirty, and uneven.

If your soldering iron is in good condi-

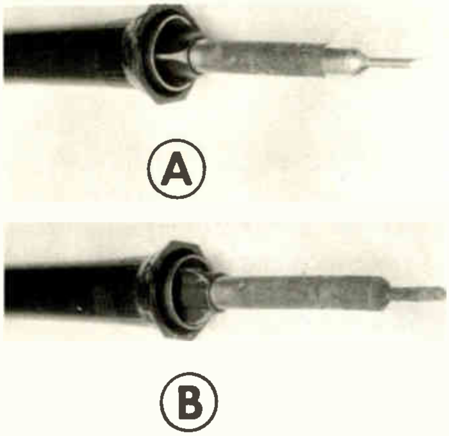

Fig. 4. If your soldering iron is new and has not been tinned as at (A), or if it has been used and is pitted as at (B), it will need tinning.

tion, like the one shown in Fig. 4A, you can plug it into an electrical outlet and start heating it. On the other hand, if you have an iron that has been used and looks like Fig. 4B, you should file the tip smooth before you start to heat it. Even though your iron may be in good condition, read the following instructions carefully, because after your iron has been used for some time, it will become pitted like the one shown in Fig. 4B. You will have to go through this procedure to re-tin it.

To file the tip of the iron, rest the iron on a vise or a similar metal support, as shown in Fig. 5. Grasp the iron in one hand and proceed to file one of the surfaces flat as shown. Try to file the surface at approximately the same angle as that of the original tip. Do not remove any more metal than is necessary, but make sure that you file the surface until all of the dark spots and holes in the surface are gone. When you have completed the operation, the tip of the iron should look as it does in Fig. 6.

After you have filed one surface of the tip, turn the iron over. In other words, rotate the iron 180°, and file the surface flat on the opposite side of the tip. Again, remove no more metal than is necessary, but make sure you file the surface until it is clean. Try to file at the same angle as the first surface, as shown in Fig. 7.

If your iron has a pyramid-shaped tip, turn the iron a quarter turn and file one of the other surfaces. Then turn the iron over and file the last surface. When you

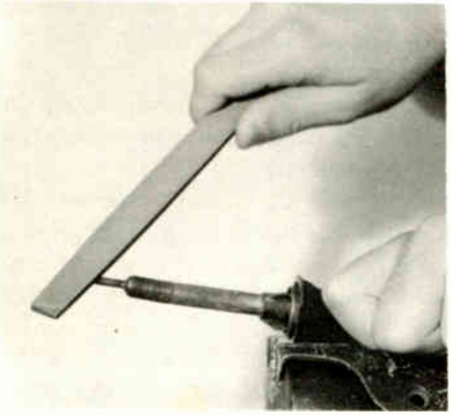

Fig. 5. To file the tip of your iron, hold it against a vise as shown here.

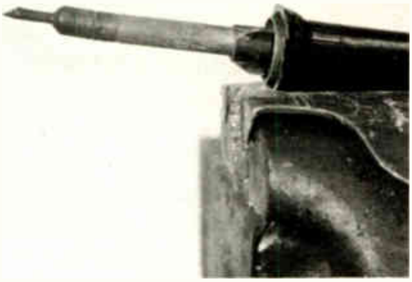

Fig. 6. When you have filed one surface, your iron should look like this.

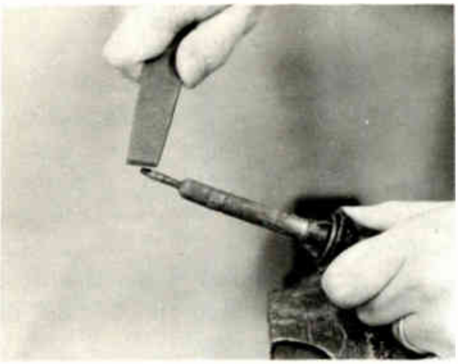

Fig. 7. File the opposite surface at the same angle as the first surface, as shown.

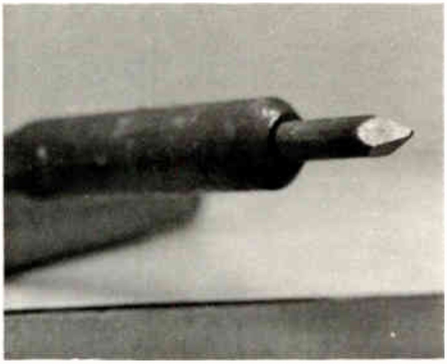

Fig. 8. Your iron should look like this after filing all four surfaces on its tip.

have filed all tip surfaces, the tip of the iron should look like the one shown in Fig. 8. Notice that the sides are approximately even.

Before you start to heat the iron, examine the edges of the flat surfaces on the tip. If the edges are rough, smooth them by careful rubbing with a piece of sandpaper.

Tinning the Iron. After you have prepared the surface for tinning, or if you are tinning a new iron that is in good condition, plug the iron in and wait for it to heat. As the iron heats, periodically touch the end of the solder to the tip so you will know when the iron is hot enough to melt the solder. You should tin it as soon as it reaches a high enough temperature, because the longer an untinned iron is heated, the more copper oxide will form on the tip.

When the iron has reached operating temperature, again rest it on a vise and lightly file one surface as shown in Fig. 5. Once you have filed the surface lightly so that it is shiny, quickly set the file down, pick up the roll of solder, and touch the end of the solder to the tip of the iron. Move the solder around the tip until the entire surface is tinned, as shown in Fig. 9. After you have tinned one surface of the tip, turn the iron and go through the same procedure of lightly filing the other surfaces, and then applying solder.

After you have tinned the surfaces of the tip, use a clean cloth to wipe off any excess solder. Hold the cloth loosely as shown in Fig. 10 to avoid burning your hand. When you have your iron tinned, it is ready for use. Unplug it, and set it aside until you are ready to start soldering.

Fig. 9. How to apply solder to tin the tip of the iron.

Fig. 10. Wiping excess solder from the iron with a piece of cloth.

Notice that the solder you received in this kit contains a rosin core that acts as a cleaning agent and prepares the metal surface to receive the solder. It is difficult to make a good soldered connection using plain solder alone; another material called flux must be applied along with the solder. Rosin flux is used in this case. Only rosin core solder should be used in soldering electronic equipment.

Hardware and other stores sell some solder with an acid core. Acid flux in any form should never be used in electronic equipment. The acid will corrode the leads and terminals and may damage some of the parts. Use only rosin core solder in electronics work; do not use liquid or paste flux. Solder similar to that which we have supplied in this kit should be used in all your electronics work.

IMPORTANT NOTICE

In checking students' problems, NRI has found that poor soldering is more frequently the cause of failure to get proper results than all other troubles combined. Therefore, be sure to perform every step in each experiment to learn all you can about soldering.

DO NOT SKIP ANY STEPS

MOUNTING THE PARTS

Most of your experiments will be carried out on your experimental chassis plate which is shown in the parts photo, Fig. 1. You will mount several parts on the chassis plate before you begin the experiments.

The parts supplied with this kit are shown in Fig. 1 and identified in the list below the photograph.

Gather the following parts and place them on your worktable. Then they will be handy when you are ready to use them:

1 Chassis plate (CH65)
1 7-lug terminal strip (ST17)
1 3-lug terminal strip (ST10)
1 4-lug terminal strip (ST28)
1 Potentiometer mounting bracket (BR1)
1 1K-ohm potentiometer (PO7)
1 Solder lug (LU1)
6 1/4" X 6-32 screws (SC1)
6 6-32 hex nuts (NU1)
1 Marking crayon (MS4)

Notice that we have supplied two sizes of screws and nuts. The size of a machine screw is given by its diameter and the number of threads per inch. The first number is the diameter. Thus, the 6-32 screws (SC1) are larger in diameter than the 4-40 screws (SC6), but the 4-40 screws have a finer thread. The length of a screw is given in fractions of an inch.

Follow the instructions as you mount the parts on your chassis and do not attach any parts until instructed to do so.

Place the chassis upright on your worktable so that the holes are positioned as shown in Fig. 11. The bent lip should be away from you and pointing upward. To

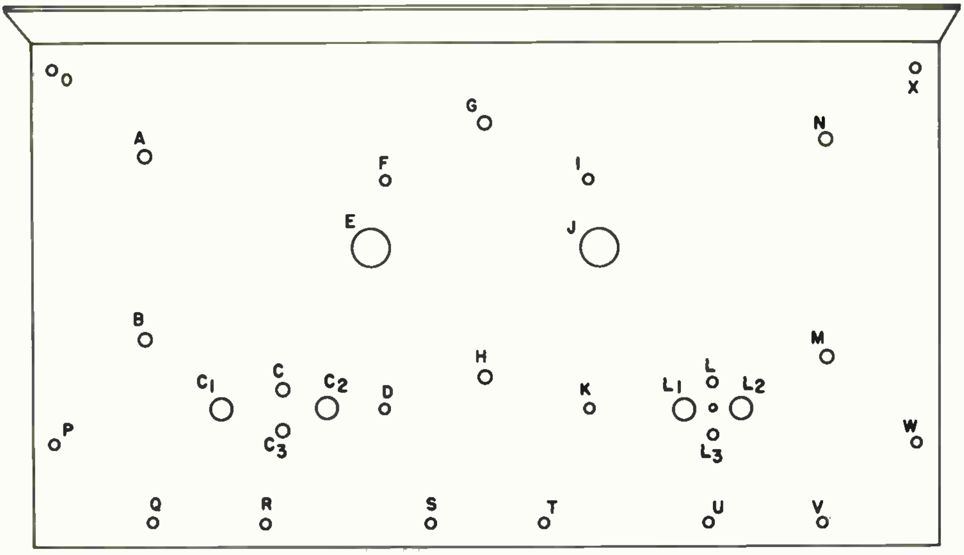

Fig. 11. Chassis hole identification.

help you locate the parts correctly, we have given the holes identifying letters. You can use the marking crayon to label these holes on the chassis. If you prefer, you can put small pieces of tape near these holes and mark on the tape with a pen.

Fig. 12 shows the chassis with the parts

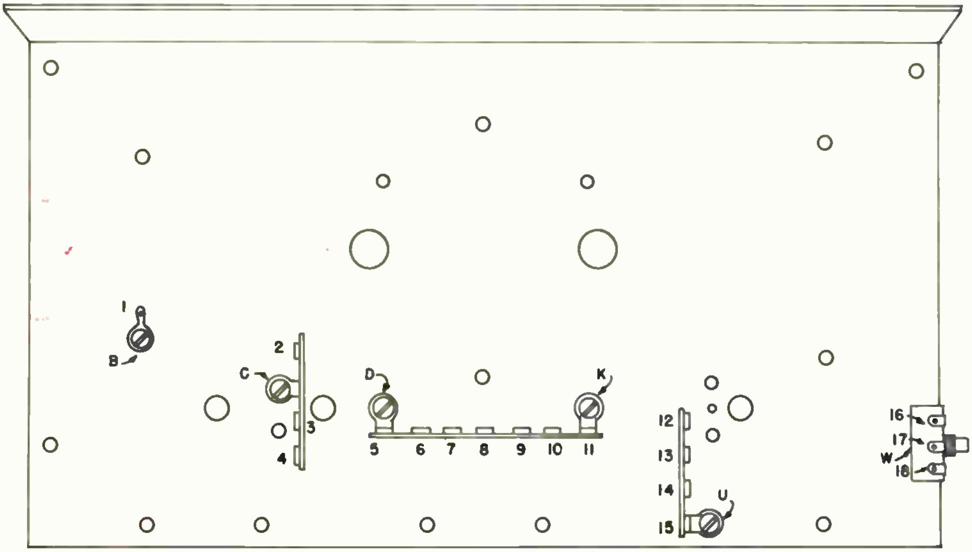

Fig. 12. Parts mounted on the chassis and the terminal identification number.

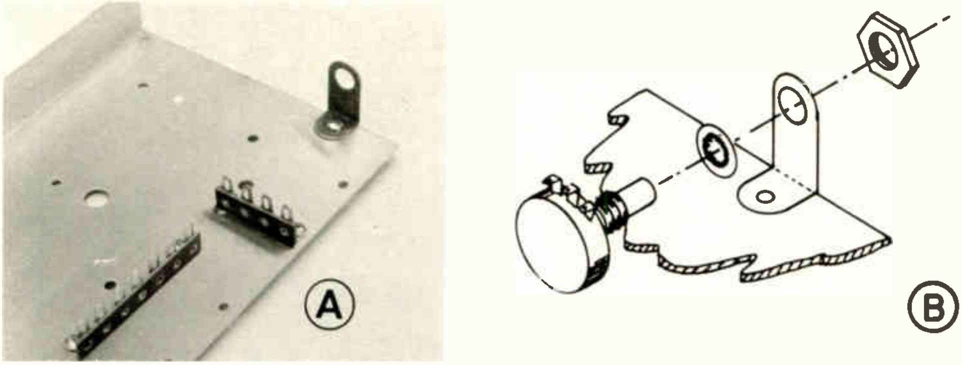

Fig. 13. (A) Mounting the potentiometer bracket; (B) mounting the potentiometer.

mounted on it. Be sure to mount the parts at the correct location and position them as shown in the drawing.

Mount the 3-lug terminal strip at hole C, as shown in Fig. 12. Pass a 1/4" X 6-32 screw down through the mounting foot in the terminal strip and through hole C in the chassis. Attach a 6-32 hex nut. Position the terminal strip as shown and tighten the screw. Hold the nut with pliers as you tighten the screw.

Install the 7-lug terminal strip at holes D and K. Use 1/4" X 6-32 screws and nuts. Position the strip exactly as shown in Fig. 12. Pass a screw down through the left mounting foot and hole D and attach a nut. Pass a screw through the other mounting foot and through hole K. Attach a nut and tighten both screws.

Mount the 4-lug terminal strip at hole U. Use a 1/4" X 6-32 screw and nut. Position the terminal strip as shown in Fig. 12 and tighten the screw.

Install the potentiometer mounting bracket at hole W. See Fig. 13A. Use a 1/4" X 6-32 screw and nut. Pass the screw down through the small mounting hole in the bracket and through hole W in the chassis. Attach the nut and tighten the screw.

Install the potentiometer in the potentiometer mounting bracket. As shown in Fig. 13B, slip the large lockwasher over the shaft and bushing of the potentiometer and slip the bushing through the hole in the bracket mounted on the chassis. Attach the large control nut, turn the potentiometer so its terminals are upward; then tighten the control nut.

Bend the solder lug at about a 45° angle, as shown in Fig. 14. Mount the solder lug at hole B, using a 1/4" X 6-32 screw and nut. Tighten the screw.

The numbers appearing in Fig. 12 are the terminal identification numbers. They will be used throughout this kit for identifying the terminals when making connections.

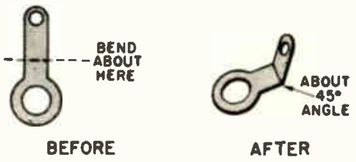

Fig. 14. Before you mount the solder lug, bend it as shown here.

Learning To Solder

Our experience in teaching students has shown that over 75% of the troubles encountered by students and technicians is due to poor soldering! You might think from this that good soldering is difficult, but this is not true. If you watch an experienced man work with a soldering iron, it looks quite simple. The experienced technician follows the two basic rules given below to make good soldering easy.

First: Have the materials to be joined and the tip of the iron clean and free from grease. If the terminals or wires are not bright, scrape them with a knife or with a piece of fine sandpaper until they are clean and bright.

Second: Have the sections to be joined hot enough to melt the solder so that it will run freely to all parts of the connection and form a good bond.

If you follow these two basic rules, you will never have soldering trouble. If you ignore them, you may spend hours looking for defective parts when the trouble is simply a poorly soldered connection.

SOLDERING TECHNIQUES

Perhaps the most important step in making a good soldered connection is to make sure that the parts you are attempting to solder together are clean. For example, if you try to solder a capacitor lead to a terminal strip, and the capacitor lead is not clean, you will find it practically impossible to get the solder to stick to the lead.

All leads, whether they are resistor or capacitor leads or merely wires to be soldered, should be tinned before you attempt to solder them. Most of the resistors and capacitors that you will receive in your kits have been tinned by the manufacturer. However, in the manufacturing processes, the tinned surface sometimes becomes covered with wax or other impurities. These leads should be cleaned and retinned whenever necessary.

You can use approximately the same procedure to tin a lead as you used to tin the tip of your soldering iron. The first step is to clean the lead. You can either scrape the lead carefully with a knife, as

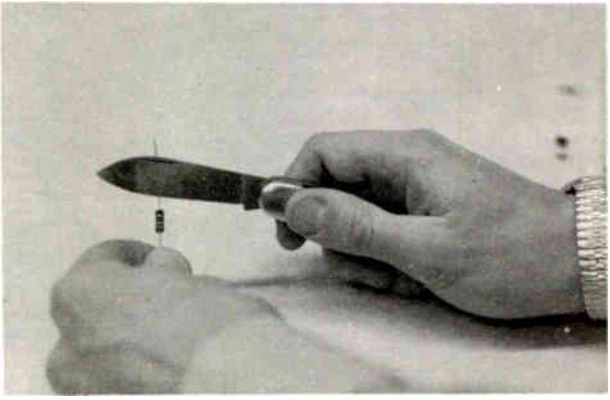

Fig. 15. How to use a knife to clean a resistor lead.

Fig. 16. Using sandpaper to clean a lead.

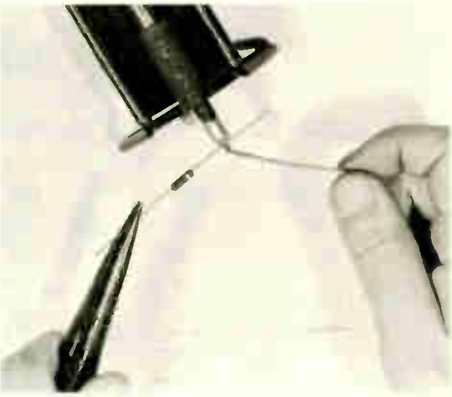

Fig. 17. How to tin a resistor lead.

shown in Fig. 15, or you can use a small piece of fine sandpaper. Hold the lead in the sandpaper, as shown in Fig. 16, and draw the sandpaper over the lead several times.

After you have cleaned the lead, hold the part with your longnose pliers and touch it to the tip of your soldering iron, as shown in Fig. 17. Then touch the solder to the lead. Allow a small amount of solder to melt onto the lead and onto the tip of the iron. Move the lead back and forth through the solder to tin the entire lead. If you apply enough heat to melt the solder thoroughly, the solder will flow smoothly over the lead, as shown in Fig. 18. Tin the other lead in the same way.

Lugs on terminal strips also should be cleaned and tinned before you attempt to solder a wire or a lead to the lug. Usually, brushing over the terminal quickly with a piece of sandpaper will remove any dirt or grease that may be on the terminal. Sometimes it will be necessary to scrape the terminal with a knife or file.

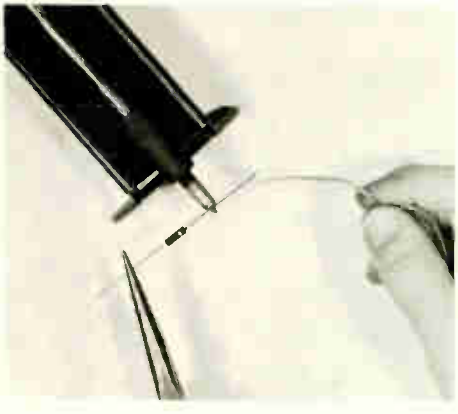

Fig. 18. A tinned resistor lead.

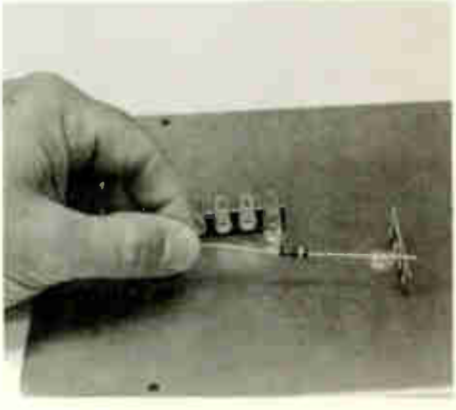

Fig. 19. Making a connection to terminal.

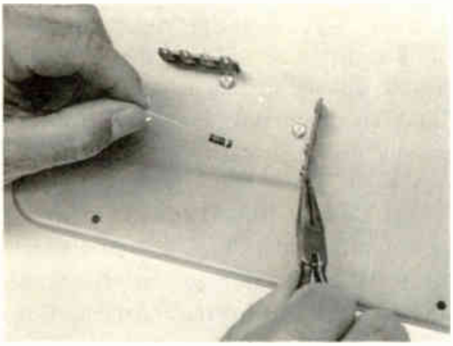

Fig. 20. Bending the lead.

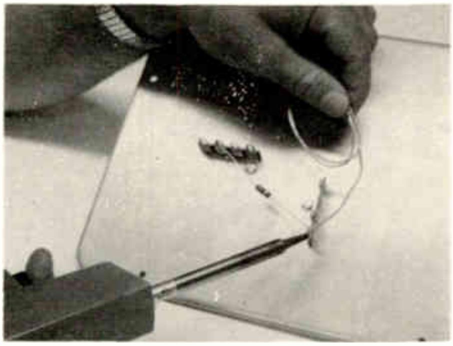

Fig. 21. Soldering a connection.

The tube socket pins and lugs on the terminal strips that you will receive in your kits have been tinned. You should have no trouble in soldering to these terminals. However, before soldering to them, carefully examine them to be sure they are clean. If they are not, clean and tin them to avoid soldering difficulties later.

To solder a lead to a terminal strip or solder lug, place the lead through the opening in the terminal lug, as shown in Fig. 19. Bend the end of the lead slightly as in Fig. 20 so that the lead can be placed in contact with the metal part of the lug. Do not wrap the lead around the terminal strip lug unless you are told to do so. This type of connection is too difficult to remove. Later, when you begin wiring equipment that you will leave assembled permanently, you will wrap the leads around the various terminals in order to insure strong mechanical and electrical connections.

When you have the lead in place, hold your soldering iron against the terminal and against the lead, as shown in Fig. 21, to heat both of them to the solder-melting point. Unless you heat them both, you will not make a good connection.

After they are hot enough, touch the end of the solder to the terminal and lead, so that the solder will flow freely over the resistor lead and the terminal. Do not use too much solder. You want only enough to cover the resistor lead and hold it to the terminal. If you use too much, the solder will flow down the terminal strip and may short to the chassis. A properly soldered connection showing the correct amount of solder is shown in Fig. 22, and a connection with an excessive amount of solder is shown in Fig. 23.

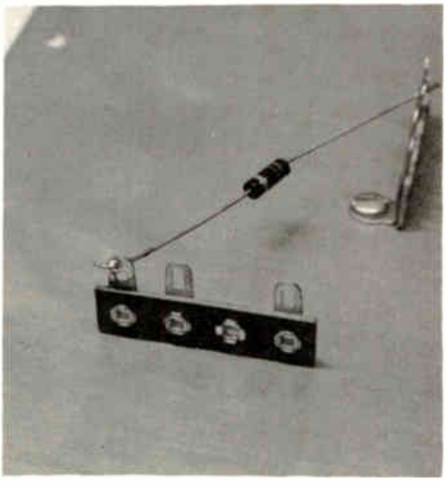

Fig. 22. Good solder connection.

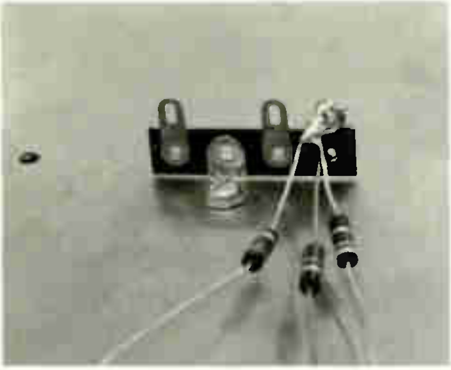

Fig. 23. Poor solder connection (too much solder).

When soldering a connection, do not be in a hurry to get the soldering iron off the connection. In most cases, it is better to hold the iron on the connection a little too long than it is not to hold the iron on long enough. When you are starting to solder, watch each connection carefully. Hold the iron on the connection long enough to allow the solder to flow freely. Solder should melt and flow in, around, and over all the leads you are attempting to solder to a terminal. The solder should also flow freely over the terminal. If you hold the iron on the terminal only long enough to melt the solder and have it start to flow, you will find that you have a rough-looking joint, and the chances are that if you apply pressure to the leads, they will pull loose. On the other hand, if you hold the iron on the joint long enough to allow the solder to melt completely and flow freely over the joint, you will have a smooth-looking connection that will be mechanically strong. This is extremely important - make sure that the solder flows freely over each connection you make.

Using Too Much Solder. Avoid using too much solder. It takes very little solder to make a good electrical connection. Usually, if you heat the terminal and lead sufficiently, you will find that a drop of solder will be all that is needed. Do not hold the soldering iron in place and simply melt more and more solder onto the joint. Once you have one drop of solder flowing around the joint, lift the solder off the terminal, but continue to heat the connection so that the solder that you have on the terminal flows around the leads and over the terminal. This may be all the solder you need. If not, add more solder and allow it to flow into the joint. If you use too much, the solder will flow between the pins and the chassis, and between the chassis and terminal strip lugs.

It is particularly important that you heat large wires thoroughly. You will often find in your radio, TV, or electronics work that you must solder transformer leads in place. Usually the leads from a transformer, particularly the leads from the filament winding on a TV replacement power transformer, will be of a fairly large size. In addition, they are made of copper, which is a good heat conductor. As a result, they can carry away a substantial amount of heat. You will have to be sure that you have the iron in good contact with the lead when making this type of connection.

Etched Circuit Wiring. Etched or "printed" circuit boards are used in many radio and TV receivers as well as in other types of electronic equipment. You can expect to have to wire and to repair circuit boards. Therefore, you should know how to do so.

Examine the etched circuit board included in your kit (NRI part EC24). This is fairly typical of the boards used in commercial equipment. The board consists of a sheet of phenolic, which is an insulating material, with a pattern of copper foil strips bonded to one side. Notice that the copper foil connects together holes in the circuit board. When parts are mounted on the board with their leads extending through these holes and soldered to the copper, the copper foil provides the electrical paths which connect the parts together to form circuitry.

We call them "etched" circuit boards because of the way the boards are made. Each board is cut from a large sheet of phenolic to which a sheet of copper foil has been bonded. The desired copper foil pattern is transferred to the board by a photographic process. The board is then placed in a highly corrosive solution which etches away the unwanted copper foil, leaving the desired foil pattern.

After the etching is completed, the board is cleaned and the holes are drilled or punched and the lettering and other markings are printed on the phenolic.

Parts are usually mounted on the phenolic side of the board and they are supported by their leads, as shown in Fig. 24. The leads are passed through the holes in the board and soldered to the foil. When you install a part, bend the lead outward slightly to hold the part until you can solder the leads. Place the tip of your iron in contact with the lead and the foil and apply solder. Allow a small amount of solder to melt and flow into and around the joint. After the solder cools, cut off the lead flush with the top of the soldered connection. Fig. 25 shows an etched circuit board with good soldered connections.

As you go through these experiments, pay particular attention to each soldered connection you make. Tin the part leads before attempting to solder them; heat each connection thoroughly; inspect each connection and wiggle the leads after it is soldered to make sure that it is a good solid connection. Try to develop sound soldering habits; they will save you a great deal of time and difficulty, not only in your experiments, but all through your electronics career.

Performing the Experiments. To get the most benefit from the experimental course, you should follow a logical, planned procedure in each experiment. When you start a new manual, always study first the introduction at the beginning of the book. Then perform the experiments one at a time, in the correct order, by observing the following procedures:

1. Read through the instructions and discussions for the entire experiment once very slowly, and study any parts that are not immediately clear to you. Do not touch a single tool or part until you make this preliminary study.
2. Lay out on your worktable the

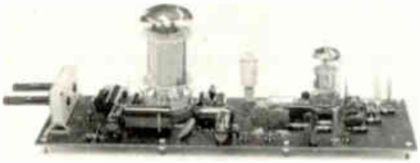

Fig. 24. Phenolic side of an etched circuit board with the parts installed.

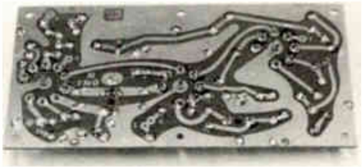

Fig. 25. Foil side of an etched circuit board, showing the parts installed.

parts and tools needed for the experiment to be performed.

3. Carry out the experiments one step at a time. Record your results whenever spaces are provided in the manual for this purpose. Additional observations and comments can be written in the margins of the pages for future reference.

4. Study the discussion at the end of the experiment very carefully, and analyze your results. After finishing an experiment, you should be able to tell in your own words exactly what you proved and how you did it.

5. Complete the Report Statement by writing the Statement Number on your Training Kit Report sheet in the space provided. Then enter the number of your choice for completing the Statement in the next column. Use the additional columns to the right for Statements that have more than one part.

6. When you have completed all ten experiments in the manual and have answered all of the statements, send in your Report Sheet for grading. Do not send in the manual.

EXPERIMENT 1

Purpose: To mount parts in a circuit; and to make soldered connections to these parts.

Introductory Discussion: Solder will hold parts together mechanically and fuse parts together so that they are, in effect, a single unit. A good soldered joint has little or no resistance and protects the surfaces of the parts from oxidation. Good soldered connections are a clue to the technician's ability. A man with an average knowledge of theory who can make good soldered connections will have less trouble than an expert on theory who cannot solder! In this experiment, you will mount parts and make several soldered connections. This experiment may seem simple, but do not pass over it quickly. The points that will be brought out are all very important.

Soldering ability is not hard to acquire and you should make this your first goal.

Experimental Procedure: Before you start the experiment, make sure your workbench is cleared so you will not lose any parts or have anything in your way. Gather your tools and the parts you will need in the experiment. At this time you should have a potentiometer, a solder lug and three terminal strips mounted on the chassis.

In the experiment, you will need the chassis with the parts mounted on it and the following parts:

3 **1000-ohm resistors (RE30; brown-black-red-silver)**
Rosin-core solder

Step 1: To prepare the parts to be soldered.

If you have the parts mounted on the chassis correctly, you are ready to wire the circuit by soldering resistors to various terminals. Plug in your soldering iron so that it can be heating.

Tin each lead of the three resistors until they are bright and shiny.

As you were instructed previously, you can use a knife or a small piece of sandpaper folded and held between the thumb and forefinger to clean the leads if they will not tin easily.

Test the iron by touching the end of the solder to the tinned tip of the iron. If the solder melts readily, the iron is ready for use.

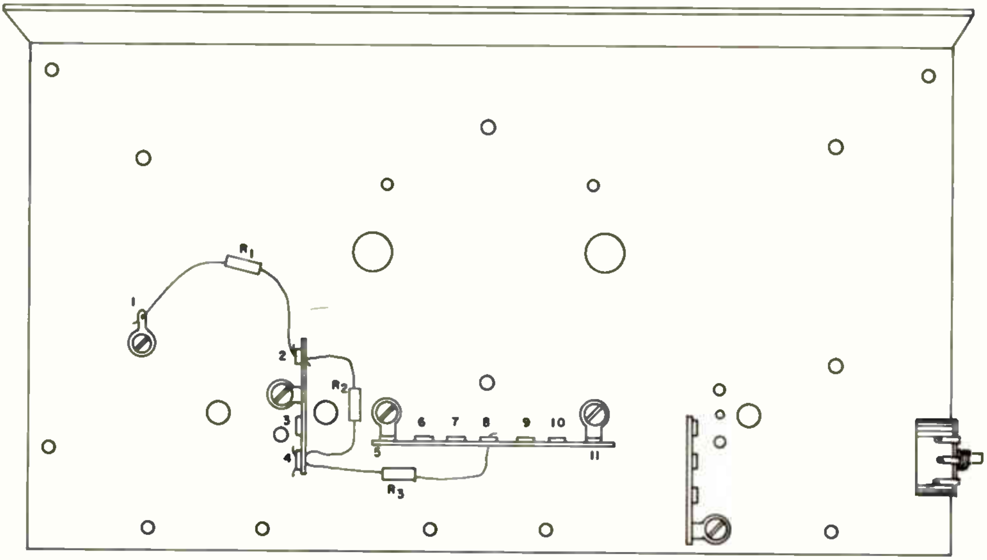

Fig. 1-1. Top view of the chassis, showing the resistors you will install in this experiment.

IMPORTANT: Do not cut the leads of any parts you received in this kit unless you are instructed to do so in the experiment. You will use most of the parts again in future experiments.

Fig. 1-1 shows you where you are to connect the resistors. The resistors are to be mounted so that the resistors and the leads are to be at least 1/2" above the chassis. As we mentioned earlier, we have given each terminal an identifying number. We will use these terminal numbers in this kit to indicate where the connections are to be made so as to simplify the instructions.

Connect the lead of one of the resistors to terminal 1, which is the solder lug mounted at hole B. Push the end of the lead through the hole in the solder lug and solder, as shown in Fig. 1-2.

Bring the tip of your soldering iron into contact with both the solder lug and the resistor lead, as in Fig. 1-2. Position the iron so that one flat surface of the tip is against the terminal. This permits maximum transfer of heat from the tip of the iron to the connection.

Touch the solder to the point where the terminal and the lead meet, and allow the solder to melt. Notice that the rosin flux flows out of the solder as the solder

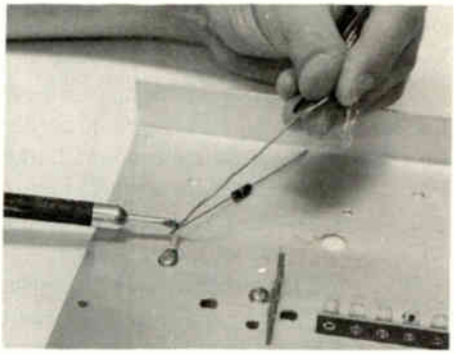

Fig. 1-2. Soldering the resistor lead to the terminal.

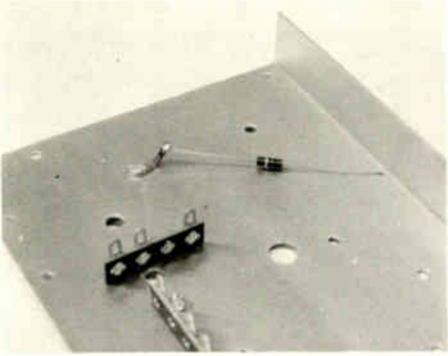

Fig. 1-3. Resistor R_1 soldered to terminal 1.

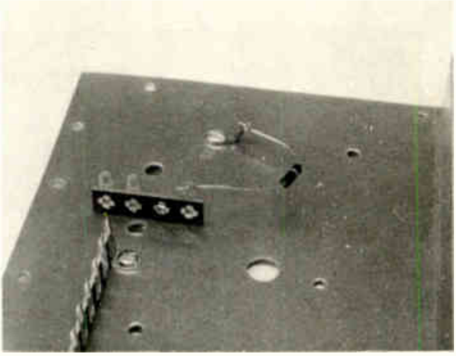

Fig. 1-4. Resistor R_1 in place on chassis.

melts. Remove the roll of solder and continue to heat the joint.

After the solder flows into the connection and coats the terminal and lead, remove the heat and allow the joint to cool and harden. Do not disturb the connection until the solder hardens.

If your solder joint is made correctly, the lead will be covered with solder where it touches the terminal and the solder should have a clean smooth appearance. Fig. 1-3 shows a good solder connection. The space between the resistor lead and the terminal is filled with solder and the solder also seals the connection.

It is a good idea to test each connection after it has cooled. To do this, grasp the resistor lead you have just soldered between the connection and the resistor body with your longnose pliers. Twist the lead gently and move it back and forth. If the lead does not move, you probably have a good soldered connection. If the lead breaks loose, or if the connection has a brown crust on it, re-melt the solder with your iron and let it cool again.

If you did make a poor solder connection, it may have been due to insufficient heat or to dirt on the lead or terminal. A poor joint can also result from your moving the lead before the joint has cooled.

Another problem which you might encounter is the "rosin" joint. This is a connection having a layer of rosin between the wire and the terminal. A rosin joint is indicated by a brown crusty appearance on the connection. You can correct a rosin joint by reheating the connection and allowing the rosin to boil out. As you heat the joint, you will see the vapor from the rosin rising from it.

With your longnose pliers, grasp the free lead of the resistor and slip it through the slot in terminal 2. Position the resistor as shown in Fig. 1-1. Twist the resistor slightly so the lead stays near the top of the slot in the terminal. Bend the end of the lead passing through the terminal so the lead touches the terminal, as shown in Fig. 1-4. Do not solder the connection at this time.

Step 2: To mount resistor R_2.

Now take another resistor and push the end of one lead about 1/8" through the slot in terminal 2. Bend the end slightly to bring it into contact with the terminal. Solder both leads to terminal 2. Place the tip of your soldering iron in contact with both leads and the terminal, with a flat surface against the terminal. Touch your solder to the connection and allow a small amount of the solder to melt. Remove the roll of solder and allow the molten solder to flow into the connection. Remove the heat and let the joint cool.

Test each connection by twisting and trying to move each lead. If the joint does not break loose, and the solder looks smooth, you probably have an acceptable connection. If not, reheat the connection, remelt the solder and allow it to cool and test the connections again.

Bend the leads of resistor R_2 at a right angle about 1/2″ from the body of the resistor and position the resistor as shown in Fig. 1-1. Connect the free lead of resistor R_2 to terminal 4. Do not solder it at this time, since another lead will be connected to the same terminal.

Step 3: To mount resistor R_3.

Connect another resistor, R_3, from terminal 4 to terminal 8. This time make the connection without detailed instructions. Bend the leads as required and position the resistor as shown in Fig. 1-1. Note that the body of the resistor should be about 1/2″ to 3/4″ from the 7-lug terminal strip. Solder and test both connections.

If you have done your work correctly, your chassis should look like Fig. 1-1. You should have a total of three resistors and four temporary soldered connections. We call them "temporary" because they can be disconnected easily, as you will see later. The solder provides both the mechanical strength and the electrical path between the leads and the terminals.

By contrast, a permanent connection does not rely on the solder for physical strength. Usually the wire is twisted or wrapped around the terminal for physical strength before the connection is soldered.

You will make only temporary soldered connections in the experiments in this manual. However, you will make permanent connections in later experiments. The instructions on how to make them will be given at that time.

Look over the connections you have made and examine them critically. Check to see if any solder has run down the terminal where it may make contact with the chassis and cause a short circuit. This condition is illustrated in Fig. 1-5. Also, look at each connection to see if solder has flowed to all parts of the joints. Look for big lumps of solder on the terminal. They indicate too little heat or too much solder.

Excess solder will do no harm, provided it does not short terminals together, short a terminal to the chassis, or contain excessive rosin. However, it looks messy and is a waste of solder. Too little heat means a poor connection; the cure is to hold the lead in position and reheat the joint.

Next you will unsolder the connections in order to learn the proper techniques for doing this.

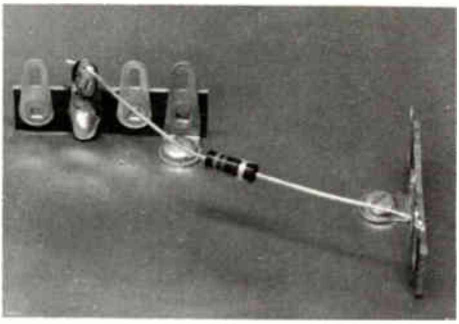

Fig. 1-5. A terminal shorted to the chassis by excessive solder.

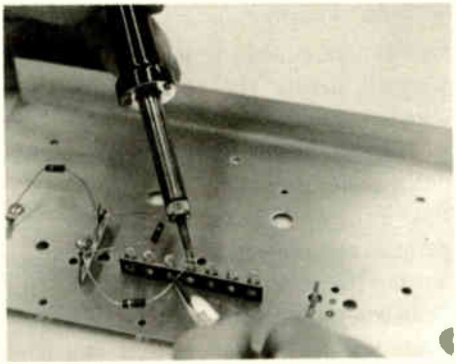

Fig. 1-6. Removing R_3 from terminal 8.

Step 4: To learn to unsolder connections.

Grasp the lead of R_3 connected to terminal 8 with your longnose pliers. See Fig. 1-6. Then touch the tip of your soldering iron to the connection. As soon as the solder melts, pull the lead out of the terminal. Wipe the tip of your iron with a cloth to remove the excess solder, and then touch the tip of the iron to the connections to terminal 4. Grasp the lead of resistor R_3 with your longnose pliers and, as soon as the solder melts, pull that lead free. Lay the resistor on your workbench. Grasp the lead of resistor R_2 connected to terminal 4. Apply heat to the terminal, and when the solder melts, pull the lead free. Wipe the excess solder from your iron with a cloth and then apply heat to the second lead of resistor R_2 which is connected to terminal 2. Remove the resistor and lay it on your work surface.

Use the procedure which we have outlined to unsolder the remaining connections and to remove resistor R_1.

Step 5: To clean parts so they will be ready for reuse.

Whenever you remove parts, clean the leads, lugs, and terminals so that you can use the parts again and connect other parts to the same lugs and terminals.

To practice this technique, first use your longnose pliers to straighten the resistor leads. Then, wipe any excess solder from the tip of your iron with a piece of cloth, and place the iron on the holder so that you can get to the tip easily. In one hand, hold a piece of cloth so that there are several thicknesses between your thumb and forefinger. With your longnose pliers in your other hand, grasp a resistor lead close to the body of the resistor. Hold the end of the lead against the tip of the iron until the solder on the lead melts, and quickly pull the hot lead through the cloth, as shown in Fig. 1-7. This will remove all excess solder and leave the lead surface clean and bright. Do this on all resistor leads that have been used in this experiment.

There are several methods of removing the solder from terminal and solder lugs. Probably the easiest and most efficient method to use on small pieces of elec-

Fig. 1-7. Removing the excessive solder from a resistor lead.

tronic equipment, such as the experimental chassis you received in this kit, is to turn the chassis upside down so that the terminals are pointing downward. Apply the tip of the iron to the end of the terminal, and when the solder melts most of it will run onto the tinned surface of the iron. Wipe the excess solder from the tip and repeat the procedure on the other lugs on the terminal strip. If a thin film of solder remains in the terminal holes, wipe the excess solder from the tip of the iron and reheat the lug. Push a resistor lead through the hole to remove the solder.

In addition to removing the solder from the terminals, this method will remove any excess solder that may be on the terminal strip lugs near the chassis.

Removing excess solder from terminals, tube socket pins and other types of solder lugs in large pieces of electronic equipment that you cannot pick up and turn upside down requires a slightly different procedure. In this case, with the terminals pointing upward, wipe the excess solder from the tip of your iron and keep the cloth in one hand while you work. Touch the tip of the iron to the side of the lug; when the solder melts, some of it will run onto the tinned surface of the iron. Wipe off the solder and keep repeating the process until all surplus solder has been removed. If you have trouble getting the solder out of the hole in a lug, heat the lug and push a resistor lead through the hole. The solder that accumulates on the resistor lead can then be easily removed.

The same procedure should be used to remove solder from tube socket pins and terminal strip lugs.

Discussion: In this first experiment, you began acquiring one of the most important skills a technician must have -- the ability to make good soldered connections. You have had practice in mounting actual electronics parts and soldering them into place. You have been able to see how solder looks as it cools and hardens. You should not expect to be an expert at soldering at this time; it takes considerable practice. However, if you carefully follow the procedures discussed in this experiment, you should have no trouble making good soldered connections and you will soon become an expert with a soldering iron.

You have also had practice in the equally important task of unsoldering, and you have learned how to clean the parts so they will be ready for reuse. This is important because often the serviceman must disconnect one part in order to check another. When you disconnect a part or lead, you should carefully prepare it and the terminal from which you removed it before resoldering the lead back into position.

Instructions for Statement No. 1: In this statement, there are two sentences to be completed, each having several choices preceded by numbers. Only one of the choices in each group correctly completes a sentence in the statement. Read the first sentence, and put a circle around the number preceding the choice that completes it. Do the same for the second sentence.

Statement No. 1: In this experiment, I used

[✓ *(1) temporary*]
(2) permanent

connections; and I found that as molten solder becomes hard, its appearance is

(1) a copper color.
[✓ *(2) a shiny gray color.*]
(3) a dull black color.

SOLDERING TIPS

Always use a clean, hot, well-tinned iron.

Always heat the junction to be soldered enough to melt the solder.

Always use a rosin-core solder.

Always tin part leads to be soldered.

Always test all leads in each joint after solder cools.

Always keep iron on joint until the rosin has boiled out of the joint.

Never try to solder dirty or untinned leads or terminals.

Never melt solder on the iron tip and carry it to the junction.

Never use acid-core solder or pastes for radio and electronic work.

Never drip solder off iron on to joint.

Never let leads move while solder is setting.

Turn now to the enclosed Training Kit Report sheet. Fill in the top part with your name, address, student number and Kit number, 1T. Write the number 1 in the first box of the column with the heading, "Statement No." This statement is in two parts. Therefore, place the number of your choice for the first part in the second column and place the number of your choice for the second part of the statement in the third column. As an example, assume that the first statement was:

San Francisco is located in the

(1) East
(2) South
(3) West

And it is in the state of

(1) Nebraska.
(2) California.
(3) New York.

The correct answers are (3) for the first part and (2) for the second part. Therefore, you would place the Statement number in the first column, the number 3 as your answer for the first part is the second column, and the number 2 in the third column.

EXPERIMENT 2

Purpose: To learn how to wire and repair etched circuit boards.

Introductory Discussion: Etched circuit boards are often used where compactness, ease of wiring or freedom from circuit variations are important. The vast majority of radio and TV receivers use etched circuit boards. Thus, it is likely that when you repair a receiver you will have to make repairs on etched circuit boards.

Etched circuit boards are fragile. They can be damaged by rough handling or poor workmanship. The phenolic will crack or break when subjected to excessive pressure. This results in breaks in the copper foil strips and produces open circuits.

The copper foil is glued to the circuit board. When overheated, the glue will weaken and the copper foil strips will pull loose from the board. However, the board will withstand a surprisingly large amount of heat before either the phenolic or the foil becomes damaged.

In performing this experiment, you will develop skill in working on etched circuit boards. This will prepare you for work on your future experimental kits and for practical work as a technician.

Experimental Procedure: In this experiment, in addition to your chassis, soldering iron and solder, you will need the following:

1 Etched circuit board (EC24)
2 22,000-ohm resistors (RE33; red-red-orange-silver)
1 7-pin tube socket (SO76)
Red hookup wire
Solder

Plug in your soldering iron so that it can be heating. Inspect the tip. If the tip is not clean, wipe it with a cloth and apply a thin coating of solder. If you wipe the tip frequently, it will last longer. Also, you will seldom have to file and retin the tip.

In this experiment, you will practice soldering to the etched circuit board and you will make repairs on the copper foil. The foil near holes A through H is for practice only. Do not be concerned if you damage it in performing this experiment. However, the remainder of the board will be used in later experiments. Therefore, you should exercise reasonable care in working on the board.

Step 1: To wire a circuit on the etched circuit board.

In order to become proficient at working on circuit boards, you will have to develop a feel for soldering to the copper foil. Before mounting any parts, you will determine how much heat the foil can withstand.

Place your etched board on your worktable with the foil side up. Touch the tip of your soldering iron to the foil near hole B. Hold the soldering iron nearly straight up with the tip at the edge of the hole, as shown in Fig. 2-1. Touch the end of your solder to a point where the tip touches the foil. Allow about 1/4" of solder to melt and flow onto the foil. When the solder spreads out smoothly on the foil, remove the heat and allow the foil to cool. Do not be concerned if the hole is covered with solder.

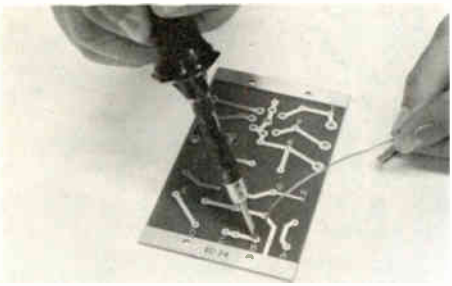

Fig. 2-1. Applying heat and solder to the foil.

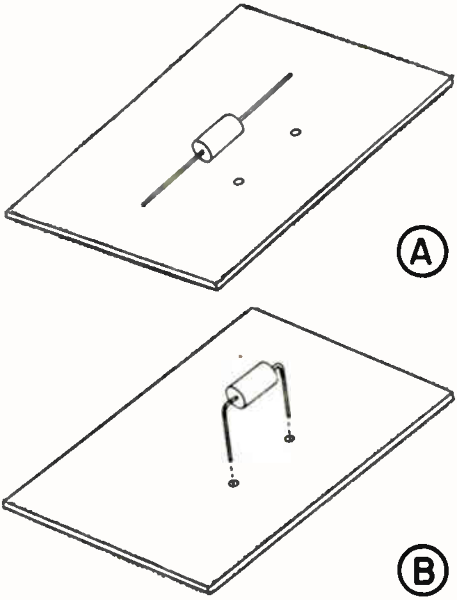

Fig. 2-2. (A) Measuring the resistor against the mounting holes; (B) resistor leads bent to correct spacing.

In a similar manner, apply heat to the foil surrounding hole A. Touch your solder to the iron and the foil and melt about 1/4" of the solder. Continue to heat the foil until the foil begins to loosen. This may take up to 15 seconds, depending upon the wattage rating of your iron and the condition of the tip. Remove the heat from the foil.

Notice that the phenolic around the overheated foil is charred slightly. Use a knife or your longnose pliers to peel the damaged foil off the board.

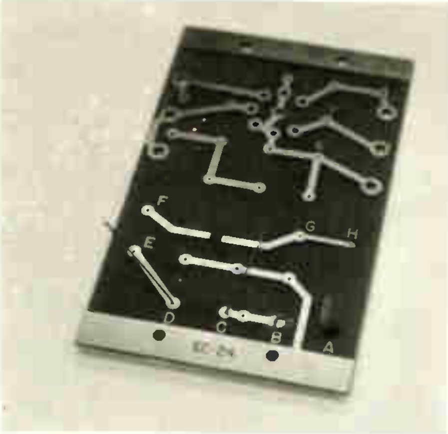

Fig. 2-3. Leads are bent outward to hold the resistor in place.

The brief experience which you have gained will give you some idea of how long it takes to make a connection and how long it takes to damage the circuit board. Next, you will mount and solder parts to the circuit board.

Install one of the 22,000-ohm resistors (red-red-orange-silver) on the phenolic side of the circuit board at holes C and D. Use the following procedure: First, "measure" the resistor against the spacing between the holes, as shown in Fig. 2-2A. In this case, the spacing between the holes is about 1/4" greater than the length of the body of the resistor, so bend both leads at right angles about 1/8" from the body of the resistor. Fig. 2-2B shows the leads ready for insertion in the holes.

Next, slip the leads through holes C and D and push the resistor down against the board. Bend the leads outward slightly, as shown in Fig. 2-3, to hold the resistor in place.

Turn the foil side of the circuit board up to solder the connections. Position the soldering iron so that the tip is in contact with both the foil and the lead. Touch the end of your solder to the point where the tip, lead and foil meet and allow about 1/4" of the solder to melt. Continue to heat the connection until the solder flows smoothly and completely surrounds the lead. Then, remove the iron and allow the connection to cool.

Finally, use your diagonal cutters to cut off the lead flush with the top of the solder connection.

Use the procedure outlined here to solder the other resistor lead to the foil.

Fig. 2-4 shows typical poorly soldered

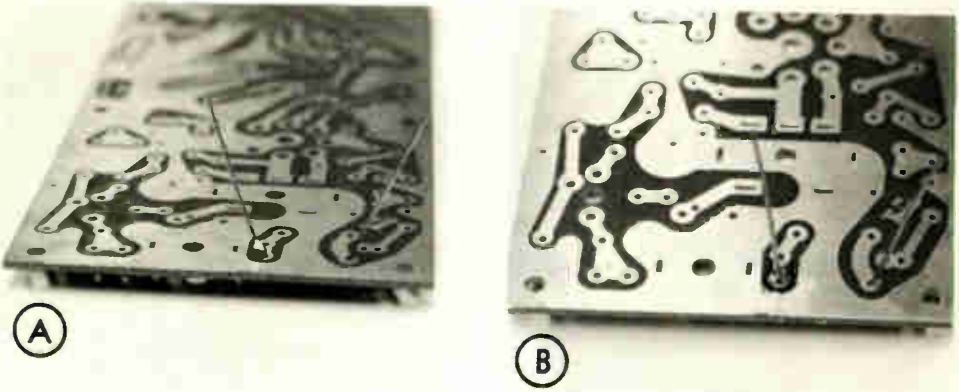

Fig. 2-4. Typical examples of poorly soldered connections.

connections. At A, too little heat was used; the solder adheres to the lead, but not to the foil. This connection could be improved by simply applying more heat. In Fig. 2-4B, too little solder was used, resulting in a minimum of strength and reliability. To improve this connection, you would apply both heat and solder.

Step 2: To demonstrate methods for removing components from etched circuit boards.

Wedge the blade of your small screwdriver between the board and the body of the resistor near hole C. (If the resistor is flat against the board, slip the screwdriver blade under the lead at hole C.) Heat the solder at hole C and lift the resistor enough to pull the lead from the hole.

Stand the circuit board on edge on your worktable. On the phenolic side of the board, grasp the lead of the resistor connected at hole D. With your forefinger and thumb pressing against the board, apply a lifting pressure to the resistor lead. Heat the connection at hole D on the foil side and when the solder melts, pull the resistor from the board and discard it.

Now you should clean the holes so that a new resistor can be installed. Heat the solder at one of the holes. While the solder is molten, insert a toothpick into the hole from the foil side of the board. Remove the soldering iron and let the foil and solder cool. When you remove the toothpick, the hole will be left clear.

Step 3: To demonstrate techniques for repairing etched circuit boards.

Cut through the foil between holes D and E to simulate a crack in the foil. You can use your pocket knife. Fig. 2-5 shows how to make a clean cut safely.

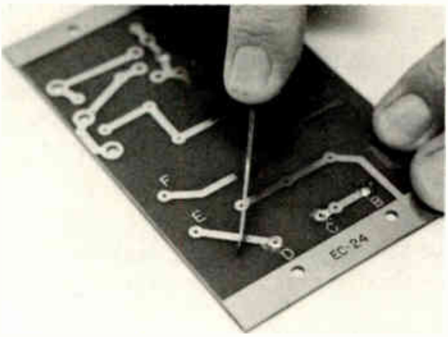

Fig. 2-5. Cutting the foil to simulate a crack in the board.

Heat the foil near the cut and melt a small amount of solder onto the foil. Use the tip of your iron to "run" the solder across the crack. The solder should adhere to the foil on both sides and bridge the narrow gap. If necessary, apply a little more solder to make a reliable repair.

A wider break, such as the one between holes F and G, requires a slightly different repair. You solder a short piece of bare wire across the break in the foil.

Remove about 2″ of insulation from a length of red hookup wire. There are several ways of removing the insulation. You can peel the insulation off with a knife, or you can cut the insulation with your diagonal cutters, knife or wire strippers and simply pull off the unwanted piece. Another technique is to crush the insulation with pliers and then peel off the pieces. When stripping the insulation off wire, it is important to avoid nicking or cutting the wire because this will weaken the wire and make it break easily.

As you did previously for the narrow break, heat the foil on both sides of the break and tin the foil with solder. Lay the bare wire across the break in the foil and solder the wire to the foil. Run solder along the wire and foil for about 1/2" on each side of the break. Using your diagonal cutters, cut off the wire beyond the solder. This should leave about 1" of wire bridging the break in the foil.

Step 4: To install parts on the foil side of the circuit board.

Bend the leads of a 22,000-ohm resistor (red-red-orange-silver) at right angles close to the body of the resistor, and insert the leads through holes C and D from the foil side of the board. Position the resistor about 1/16" to 1/8" from the board. This will leave room for soldering the connections. Bend the leads outward slightly to hold the resistor in place.

Solder one lead of the resistor to the foil. Apply heat to both the foil and the lead and apply solder. Allow the solder to flow freely over the connection. Remove the heat and let the joint cool. In a similar manner, solder the other resistor lead to the foil. You will use this resistor in later experiments, so do not cut off the leads! (Normally, after installing a part from the foil side as you have just done, you would clip off the excess lead length on the other side of the board.)

Locate the 7-pin tube socket. The socket has 7 pin connections and a center locating pin. You will install the tube socket on the *foil* side of the circuit board instead of from the phenolic side. Align the pins over the holes on the circuit board. Notice that there is an open space between the pins. Install the socket on the board by pushing firmly. When the socket is properly installed, the pins project about 1/16" on the phenolic side of the board.

With the socket in position, you are ready to solder. Since the tube socket pins on the phenolic side of the board will become quite hot as you solder them to the board, it would be a good idea to lay the board on a newspaper to protect your worktable. Hold the soldering iron so the tip is at the junction of the foil and a pin of the tube socket.

The flat surface of the soldering iron tip should be turned toward the pin. Apply solder to the foil and to the pin. Melt about 1/4" of solder and let it flow around the pin. Solder should adhere to one half or more of the perimeter of the pin and to the foil. Remove the heat and let the solder cool. In the same manner, solder the six remaining pins of the tube socket. Do not try to solder the center locating pin. Fig. 2-6 shows the socket soldered in place.

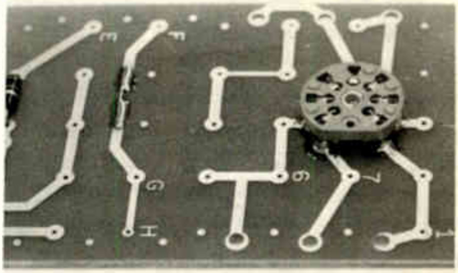

Fig. 2-6. Tube socket mounted on the etched circuit board.

Discussion: In this experiment, you have experienced working on a typical etched circuit board. You learned that you can solder to the circuit board with a moderate amount of heat. If the iron is clean and tinned, a connection can be soldered in a matter of seconds; it takes a considerable length of time to overheat and damage the circuit board.

In Step 2, you learned how to install components on the circuit board. First, you determined the lead spacing and bent the leads so you could insert the leads in the holes; then you pushed the part down against the circuit board and bent the lead to hold the part in place. Then you soldered the connection, allowed it to cool, and cut off the excess lead length, close to the soldered connection. In a good solder connection, the solder adheres to both the lead and to the foil and the solder has a smooth appearance.

You also learned how to remove parts from the etched circuit board. This is important because frequently you will have to disconnect a part to make tests and when you determine which part is bad, you will have to replace it. Before replacing a lead, clean the hole in the board. Otherwise, you may break the foil loose when you try to insert the lead.

In Step 4, you learned how to install parts on the foil side of the board. This is useful because you will sometimes find it easier to replace a part on the foil side of the board. Also, interconnecting jumper wires are sometimes connected on the foil side of the board in some pieces of equipment.

The circuit board with the tube socket attached will be used in later experiments.

Instructions for Statement No. 2: In order to answer the Report Statement for this experiment, you will have to make a few connections on your etched circuit board and trace the connections. You will need your red hookup wire.

Cut a 2" length of hookup wire and remove about 1/4" of insulation from each end. Push one end through hole E from the phenolic side of your circuit board. The holes are identified on the foil side of the board. Bend the wire and push the other end through hole F from the same side of the board. Solder both connections.

Cut a 3" length of hookup wire and remove about 1/4" insulation from each end. Push one end of the wire through hole G and push the other end through the hole identified by the number 7 from the phenolic side of the board. Solder both connections.

Trace the connections on the circuit board and answer the Report Statement. After you have completed the Report Statement, unsolder and remove the resistor and the pieces of hookup wire. Clean the holes which you used on your circuit board and clean and straighten the resistor leads.

Statement No. 2: When I traced the wiring, I found that the resistor

[✓ *(1) was*]
(2) was not

electrically connected to the tube socket.

Using Schematic Diagrams

To service any type of electronic equipment, the technician must know how the parts are connected in the circuit.

The electrical connections in a circuit can be shown by means of a schematic diagram. In a schematic diagram, symbols are used to indicate the various parts, and the connections between the parts are shown by lines.

You have already seen many of the symbols used in schematic diagrams in your lesson texts. You have also seen some simple schematic diagrams. It is extremely important for you to become familiar with the various symbols used, and also to learn how to read schematic diagrams. You will have to use this type of diagram throughout your career, because manufacturers of electronic equipment seldom supply pictorial wiring diagrams. Even if you have a pictorial diagram, it is far easier to work from a schematic once you learn how to use it.

In your experiments, you will start first with simple schematics, and gradually work up to more complex ones. In time, you will be as much at ease reading a complex schematic diagram as you are reading your evening newspaper. You will soon learn the value of this type of diagram and see how much easier it is to use than the pictorial type.

SYMBOLS USED

Before you can read schematic diagrams, you must be able to recognize the symbols used in them. Fig. 26 shows the symbols commonly used to represent resistors, capacitors, and ground connections. Study these symbols so that you will be sure to recognize them the next time you see them. You will use them in these experiments.

Fig. 26. Symbols often used in schematics.

Connections and Crossovers. Often in a schematic diagram, one lead crosses over another. In some cases, there will be a connection between the two leads; in other cases, there will be no connection. There are three different systems in use to indicate whether or not there is a connection; the one that is used in any particular diagram depends on the preferences of the person making the diagram. You might think that this would be confusing, but it is usually very simple to see which system has been used.

Fig. 27 shows the three systems. Notice that in System 1 when there is a dot used on some crossovers and no dot used on the others, the dot indicates a connection, and the crossover without the dot indicates that there is no connection.

In System 2, a straight crossover is used to show a connection, and a loop is used to show no connection. You can easily tell when this system has been used. If you notice some crossovers with the loop, and some without the loop, you know that the straight crossovers represent connections, and the crossovers with the loop indicate no connection. Similarly, if you see some crossovers with dots and others without, you will know that System 1 has been used.

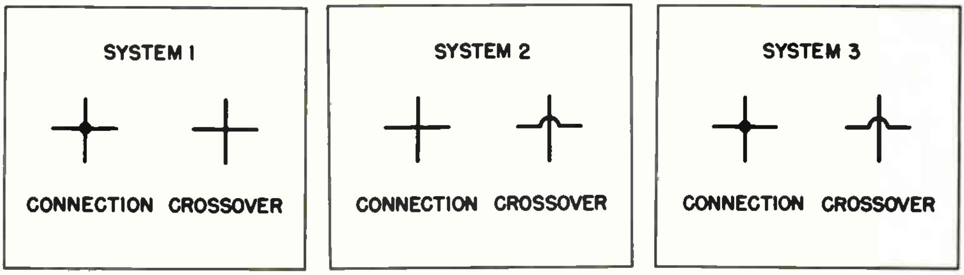

Fig. 27. Three systems used on schematics to show connections and crossovers on wires.

System 3 is a combination of the first two. We will use this system in the drawings in the experiments. The crossover with a dot indicates a connection. The crossover with a loop indicates no connection. Study these three systems - become familiar with them now, and you will have no trouble later.

Tubes. The various symbols used to represent the elements in a tube are shown in Fig. 28. The symbol for the heater is shown at A, the symbol for the cathode at B, for the grid at C, for the plate at D, and for the whole tube at E. This tube is called a triode - it has three elements plus a heater. Notice the little numbers beside each of the elements. These tell you which pin each element is connected to inside the tube. The tube we have shown is a 6C4. In this particular tube, the plate is connected to pins 5 and 1; the grid to pin 6, the cathode to pin 7, and the heater to pins 3 and 4. Nothing is connected to pin 2.

Diodes. The symbol for a semiconductor diode is shown in Fig. 29. The two elements of a diode are the cathode and the anode. The "arrow" in the symbol points toward the cathode terminal.

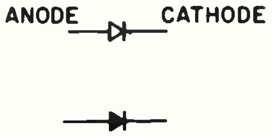

Fig. 29. Schematic symbols for a semiconductor diode.

Transistors. There are several types of transistors in wide usage. The symbols for two types are shown in Fig. 30. At A and B, we have bipolar transistors. As you can see, the only difference between the NPN and PNP symbols is the direction of the arrow. The e, b, and c labels identify the emitter, base and collector of both transistors.

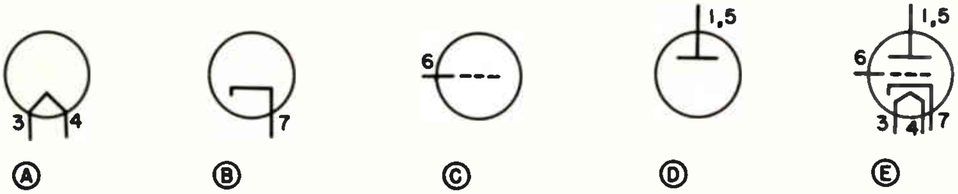

Fig. 28. Symbols used to represent the elements in a tube. Shown is tube type 6C4.

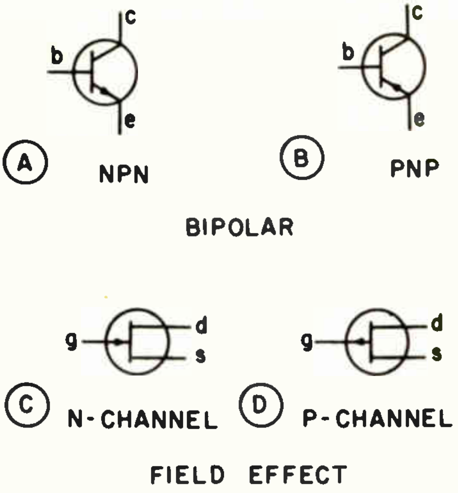

Fig. 30. Schematic symbols for transistors.

The symbols for junction field-effect transistors (FET's) are shown in Figs. 30C and 30D. You can see that the direction of the arrow is toward the junction for the N-channel and away from the junction for the P-channel FET's. In both cases, the s, g and d represent the source, gate and drain terminals. You will learn other transistor symbols later in your course.

Meters. Fig. 31 shows symbols used to represent meters on schematic diagrams. In the symbols in Fig. 31A, the letters inside the circle indicate the type of meter: V for voltmeter, μa for microammeter, ma for milliammeter, and ohm for ohmmeter. Fig. 31B shows semipictorial symbols that are sometimes used.

READING A SCHEMATIC

When working with schematic diagrams, you must remember that the schematic diagram shows the electrical connections, not the actual physical connections. An example of this can be seen in Fig. 32A. The schematic diagram shows the capacitor C_1 connected on the left to resistor R_1. From the junction of these two components there is a line going to the plate of the tube V_1.

In your work you will be interested only in the electrical connections. It will be unimportant to know whether the capacitor and resistor are first connected together and a lead run from the junction of the two to the tube socket, or whether the two are connected directly to the tube socket. Electrically both connections are the same.

The other side of capacitor C_1 is connected to the grid of the tube marked V_2. The schematic diagram shows C_1 connected to R_2 and then a line going from the junction over to the grid. The pictorial wiring diagram shows that both the capacitor and the resistor are connected directly to the grid terminal on the socket.

Notice on the schematic diagram that the lower end of resistor R_2 is connected to ground. In the wiring diagram, we see

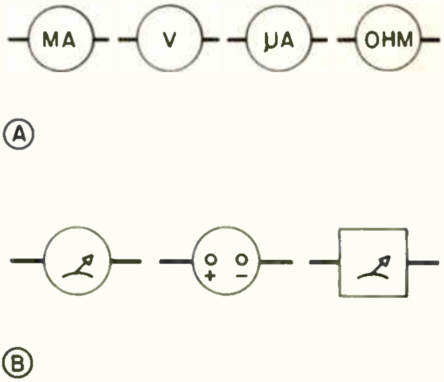

Fig. 31. Symbols used on schematics to represent meters.

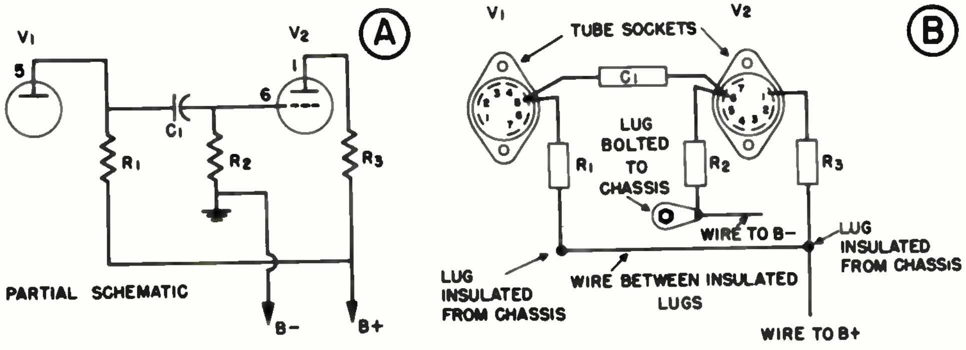

Fig. 32. (A) A schematic diagram; (B), actual wiring diagram of the same circuit.

that R_2 connects to a lug that is bolted to the chassis. Any number of ground connections can be made in this way to the chassis. When this is done, the chassis is used as part of the circuit; the chassis connects directly to B-. In some equipment the chassis is not used as part of the circuit. You will see later how to tell from a schematic diagram whether or not the chassis is part of the circuit. This information will be given to you on the schematic diagram.

Study Fig. 32 carefully. Find an electrical circuit on the schematic diagram, and then trace out the circuit on the pictorial wiring diagram. This will be valuable practical experience for you and will help you to become familiar with schematic diagrams.

EXPERIMENT 3

Purpose: To obtain practical experience in wiring from a schematic diagram.

Introductory Discussion: Fig. 3-1 is a pictorial diagram showing the actual physical location of the parts in the circuit you will wire in this experiment.

Fig. 3-2 shows the same circuit in schematic form. The circuit is that of a simple power supply. If an ac voltage were connected between terminals 1 and 2, a variable positive dc voltage would be available between terminals 17 and 15.

In a simple circuit of this type a pictorial diagram may seem easier to follow than a schematic diagram. However, a glance under the chassis of any electronic device will show how complex the pictorial diagram would become. In fact, it would be practically impossible to show how the parts are connected with a photograph or pictorial drawing. On the other hand, it is easy to show the connections with a schematic diagram.

Experimental Procedure: In this experiment, in addition to the chassis with the terminal strips and potentiometer mounted on it, you will need:

3 1000-ohm resistors (RE30; brown-black-red-silver)
1 Silicon diode (SR12)
Hookup wire
Solder

As you can see in Fig. 3-1, the diode appears similar to a resistor and is somewhat smaller. The diode is a semiconductor device which passes current in one direction only. Current can pass from cathode to anode but not from anode to

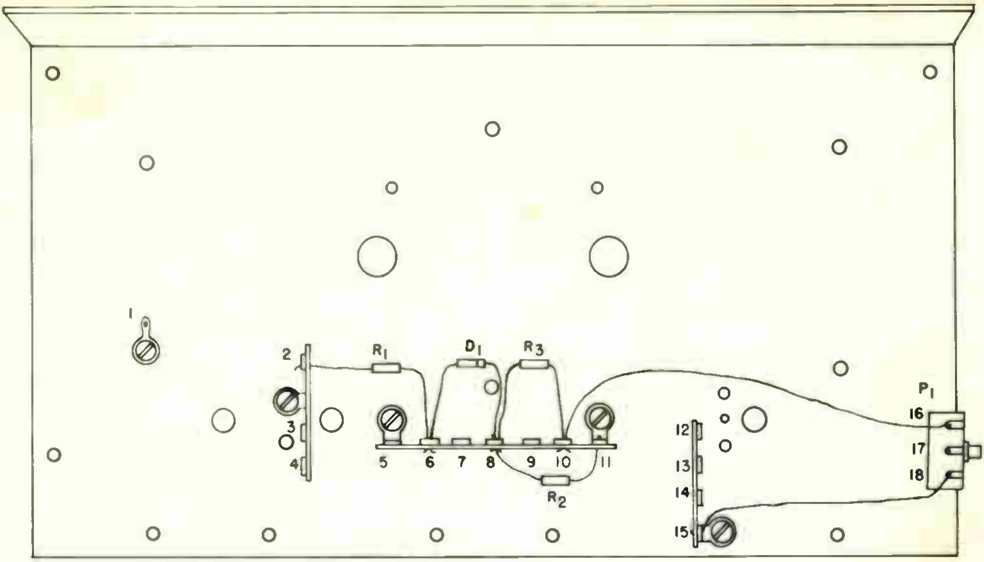

Fig. 3-1. Pictorial diagram of the circuit used in Step 1.

cathode. Thus, the diode is capable of rectifying an ac voltage.

The cathode and anode terminals of a diode are identified in one of several ways. You will usually find colored bands or a plus sign near one end of the diode, or one end of the diode may be tapered. The band, taper or other markings indicate the cathode lead of the diode as shown in Fig. 3-3.

Step 1: To determine what connections are to be made.

First, carefully study Fig. 3-2. Resistor R_1 is connected between terminal 2, which is the "input" terminal, or the terminal to which the ac voltage would be applied, and the diode D_1. The cathode lead of diode D_1 is connected to resistors R_2 and R_3. One lead of R_2 is grounded.

Resistor R_3 is connected between the junction of diode D_1 and resistor R_2 and the potentiometer, **P_1**. Potentiometer **P_1** is connected between R_3 and ground.

Notice the ground symbols on the diagram. The metal chassis forms the common connection between the ground points.

Where possible, leads of the parts which are wired together are connected to a common terminal. For example, the cathode lead of D_1, one lead of R_2 and one lead of R_3 can all be soldered to the same terminal.

When instructed to use hookup wire, cut a length of your red wire and remove about 1/4" of insulation from each end before making the connection. See that the insulation is about 1/16" back from the actual solder connection. Never try to solder to the insulation.

When we instruct you to use a short length of bare wire, use your wire strippers, diagonal cutters or longnose pliers to remove the insulation from a short length of hookup wire.

In the next step, you will perform the actual wiring.

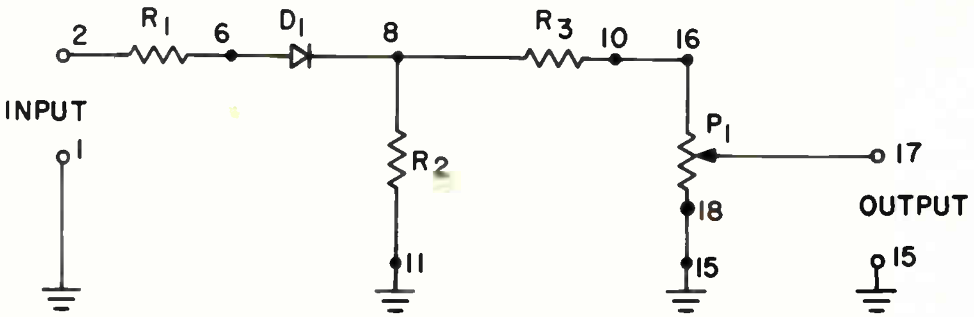

Fig. 3-2. Circuit used in Experiment 3.

Step 2: To wire the circuits from the schematic diagram.

In this step, you will mount the parts and connect wires between them to form the circuit shown in the schematic diagram in Fig. 3-2.

Connect resistor R_1 to terminals 2 and 6 as shown in Fig. 3-2. You can choose any of the three resistors since they are all the same value. Bend the leads so that the ends are spaced properly to slip through the slots in terminals 2 and 6. Slip the leads through the terminals and solder terminal 2.

Connect the diode to terminals 6 and 8 with the proper polarity. The cathode and anode leads are identified in Fig. 3-3. The cathode lead of each diode is on the right. Connect the cathode lead to terminal 8 and connect the anode lead to terminal 6. Solder terminal 6.

On the schematic diagram, notice that the cathode lead of the diode and one lead of resistor R_2 are connected together. Also, R_2 is connected from the junction with the diode lead to ground. Therefore, connect R_2 between terminals 8 and 11 as shown in Fig. 3-1. Solder terminal 11.

Next connect resistor R_3. On the schematic, this resistor is connected between the junction of diode D_1 and resistor R_2 and terminal 16 of the potentiometer. For convenience, we connect the resistor between terminals 8 and 10 and use hookup wire to complete the connection.

Install the resistor and solder terminal 8. Connect a length of hookup wire from

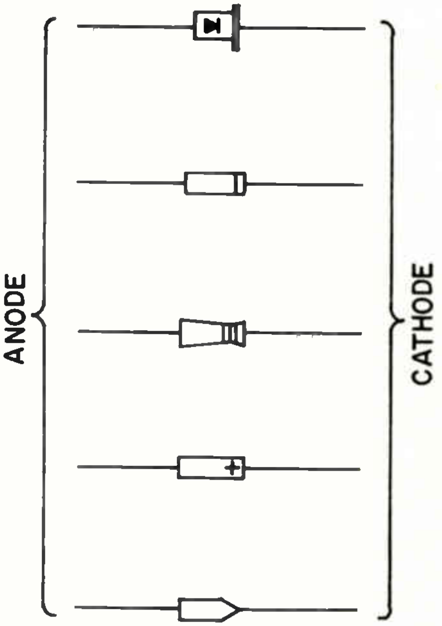

Fig. 3-3. Methods used to identify the leads of semiconductor diodes.

terminal 10 to terminal 16 and solder both connections.

The potentiometer is connected between resistor R_3 and ground. Thus, we must ground terminal 18. Again, we choose a convenient grounded terminal, which is terminal 15. Connect a length of hookup wire from terminal 18 to terminal 15 to complete the wiring. The center terminal of the potentiometer, terminal 17, is the "output" terminal.

This completes your wiring. You should have made all of the connections shown in Fig. 3-1. To make certain, check your wiring as follows:

1. There should be a resistor, R_1, between terminals 2 and 6.
2. Diode D_1 should be connected between terminals 6 and 8, with the cathode lead to terminal 8.
3. Resistor R_2 should be connected between terminals 8 and 11.
4. Resistor R_3 should be connected between terminals 8 and 10.
5. There should be hookup wire from terminal 10 to terminal 16 on the potentiometer.
6. There should be a length of hookup wire from terminal 18 on the potentiometer to terminal 15.

You should make a habit of checking your connections in this way each time you finish wiring a circuit. By checking your work, you may find and correct errors that could be serious or difficult to find later. When you check your work, pay particular attention to the soldered connections. Be sure that all connections are soldered properly. If not, resolder them.

When you are satisfied with your work, unsolder all of the connections and remove the parts. Straighten the resistor and diode leads and remove the excess solder from all terminals. Use the techniques you learned in Experiment 1.

Remove the 1000-ohm potentiometer from the mounting bracket and carefully clean the terminals. Remove the potentiometer mounting bracket and put it with the potentiometer. You will use these in a later Training Kit.

Discussion: In this experiment, we have taken you step-by-step through the wiring of a circuit from a schematic diagram. You have checked your work by comparing the actual parts layout with a list of the connections and with a pictorial diagram. This layout is not the only one that could be made from the schematic of Fig. 3-1. The same electrical circuit could have been made with the leads routed along different paths.

You should practice drawing schematic diagrams because such practice will help you to become more familiar with schematic symbols and will aid you later in tracing circuits. You need not start with elaborate diagrams; simple circuits like those shown in this experiment will be satisfactory.

The schematic diagram shows electrical connections only. Therefore, additional information is needed in order to wire more complex circuits. Experienced technicians usually sketch a layout before wiring. However, once a circuit is wired, it is easy to trace the circuit by following the schematic diagram.

Instructions for Statement No. 3: This statement is a test of your ability to relate a physical parts layout to a schematic diagram of that layout. Fig. 3-4 shows a circuit wired on your experimental chassis using resistors, a diode and a potentiometer.

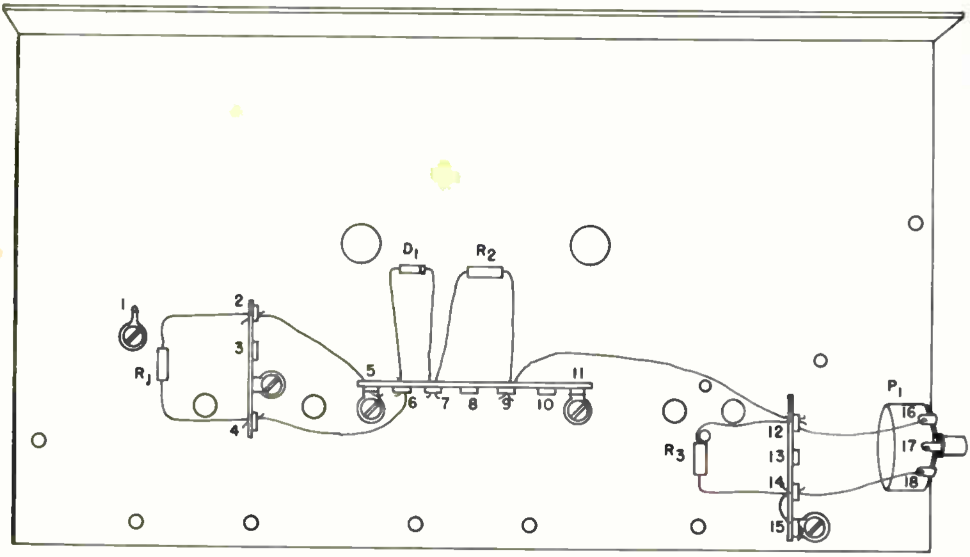

Fig. 3-4. Pictorial diagram of the circuit shown in Statement 3.

Study this circuit carefully and compare the arrangement with the four schematics in Fig. 3-5. When you are certain you have the schematic which corresponds to the circuit of Fig. 3-4, complete the statement here and on your Report Sheet.

Statement No. 3: The schematic diagram of the circuit in Fig. 3-4 is Fig. 3-5:

[✓ *(1) A*]
(2) B
(3) C
(4) D

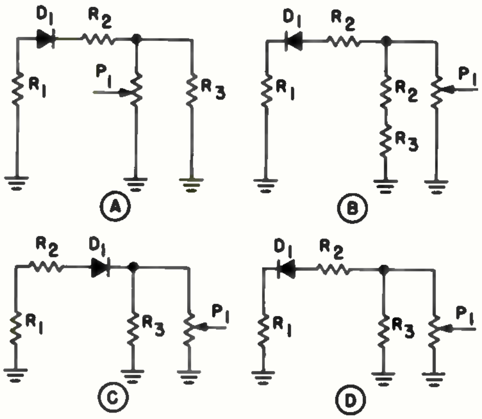

Fig. 3-5. Schematics for use with Statement No. 3.

IDENTIFYING RESISTORS

As you go ahead with your experiments, and when you work on your own, you will need to be able to identify the value of resistors.

Although the value is stamped on some resistors, on most 1/2-watt, 1-watt, and 2-watt resistors the value is indicated by means of colored bands on the resistor. You should learn to read this color code so that you can identify resistors quickly.

The colored bands on the resistor usually are nearer to one end than the other. Thus, to read the color code, turn the resistor so that the colored bands are toward the left end of the resistor as shown in Fig. 33.

Each color represents a number. These are given in Fig. 33. The first band, labeled A, gives the first figure in the value; the second band, labeled B, gives the second figure in the value; the third band, labeled C, gives the number of zeros after the second figure in the value, and the fourth band gives the tolerance of the resistor (silver for ±10% tolerance, gold for ±5% tolerance). If the tolerance is ±10%, it means that the actual value of the resistor may be as much as 10% higher or lower than the value indicated. If it is ±5%, the actual value may be up to 5% higher or lower than the value indicated.

COLOR	FIGURE
BLACK	0
BROWN	1
RED	2
ORANGE	3
YELLOW	4
GREEN	5
BLUE	6
VIOLET	7
GRAY	8
WHITE	9

COLOR A GIVES FIRST FIGURE OF RESISTOR VALUE.

COLOR B GIVES SECOND FIGURE OF RESISTOR VALUE.

COLOR C GIVES THE NUMBER OF CIPHERS FOLLOWING THE FIRST TWO FIGURES.

COLOR D GIVES THE TOLERANCE

GOLD BAND INDICATES ±5%
SILVER BAND INDICATES ±10%
NO BAND INDICATES ±20%

Fig. 33. Standard resistor color code.

Some resistors may have a fifth color band. This band will follow the tolerance band (to the right) and is used to indicate a military reliability level. The fifth band will be Brown, Red, Orange or Yellow which indicate increasing percent of reliability. In your work you can simply ignore the fifth band.

To find the value, you need to look only at the first three bands. For example, suppose you have a resistor color-coded red, red, and black. Referring to the chart, you see that red represents 2. Therefore, the first two figures in the value are both 2. As we have said, the third band indicates the number of zeros in the value. Since black represents 0, when the third band is black, there are no zeros in the value. So the value of the resistor is 22 ohms.

If the resistor had been color-coded red, red, and brown, the first two figures would again be 2. Brown represents 1, so there would be one zero, and the value would be 220 ohms. Red, red, and red would indicate a value of 2200 ohms (often written 2.2K ohms, where the K stands for 1000); red-red-orange, a value of 22,000 ohms (often written 22K-ohms); red-red-yellow, a value of 220,000 ohms (or 220K ohms or .22 meg; a megohm is 1,000,000 ohms); red-red-green, a value of 2,200,000 ohms (or 2.2 megohms); and red-red-blue, a value of 22,000,000 ohms (or 22 megohms).

Look over the resistors you have received, and practice reading the color codes on them. You can check the values by referring to the parts list given in Fig. 1. In the next experiment you will have some practice in picking out resistors of different values.

EXPERIMENT 4

Purpose: To construct a circuit using only a schematic diagram for guidance.

Introductory Discussion: If you read construction articles in any of the radio-TV-electronics magazines, you will see that step-by-step wiring instructions are rarely given; you work from a schematic diagram. Thus, if you wanted to build some of this equipment, you would have to work out the placement of the parts and other details for yourself.

We want you to become so familiar with schematic diagrams that you can look at one and picture the arrangement of the parts. That is not hard if you start with simple circuits like those you have built so far, and gradually work up to more complex circuits. The manufacturer's servicing information on any equipment usually has a complete schematic diagram and the parts values. If you are servicing the equipment, you will have to find the defective part, determine its value, and make the replacement.

Usually connections between parts are shown by a line that follows the shortest path between the two parts. However, this is not always true. The only sure way to find the part is to trace the circuit. Often it is more convenient to run a lead over a somewhat longer path to avoid crowding a section of the diagram. An example of this is given in Fig. 4-1. We could have drawn a horizontal line directly from pin 4 of V_1 to pin 3 of V_2 to show that they are connected. However, the line would have had to cross a number of other lines, thus crowding the diagram, and perhaps causing some confusion. Drawing the line as in Fig. 4-1 avoids confusion.

Tracing circuits on a schematic diagram is in many ways like tracing a road between your home and another city on a

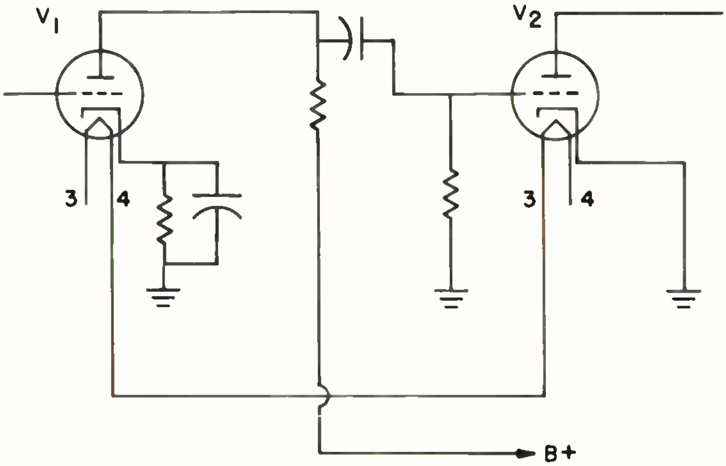

Fig. 4-1. Typical schematic diagram showing a two-stage tube circuit.

road map. You will seldom find a road that goes in a straight line from one place to another. Instead, the road will turn time and time again; you may have to go a certain distance on one road and then turn onto another. So it is in tracing the circuit on a schematic diagram. You start at one point in the circuit and trace toward another point. You may find a direct circuit between the two points, but more often you will find the circuits are connected by something other than a direct connection. In addition, you may find that to get from one point to the other you have to trace the circuit to some intermediate point, and then from that point on through an additional circuit to the point that you are interested in reaching.

Frequently in service work you will have to trace out the actual wiring in a receiver and compare the wiring with a schematic diagram. We cannot stress too strongly how important it is for you to learn to use this type of diagram. This is why we will concentrate on learning how to use diagrams.

When you work from a schematic diagram in the experiments, there may be several ways in which the various leads can be run. In general, try to use the shortest possible route. When we work on the more complicated circuits, we will give detailed instructions on exactly where to place each important lead; but during these early experiments, we will leave you on your own as much as possible to give you all the practical experience we can.

When you build equipment from a schematic diagram, you should carefully check each circuit you wire to make sure it is wired correctly. Also make sure that each connection is properly soldered. Even if you learn to work from a schematic, the equipment you build will not work properly unless all connections are properly soldered. Many people waste a great deal of time because of careless wiring and poorly soldered connections, which could easily have been spotted if a little extra time had been taken to check the work. Start right now by checking each circuit you wire against the schematic diagram and by checking each soldered connection you make. These are good habits, and the sooner you acquire them the better.

Experimental Procedure: For this experiment, in addition to the chassis with the solder lug and terminal strips, you will need the following:

1 1000-ohm resistor
1 22,000-ohm resistor
1 100,000-ohm resistor
2 1/4" × 4-40 screws
2 4-40 hex nuts
1 Etched circuit board (EC24)
Hookup wire
Solder

Use the resistor color code chart shown in Fig. 33 to help identify the three resistors used in this experiment.

Check your experimental chassis and make certain that the terminals are clean and all excess solder has been removed. At the same time, check the tip of your soldering iron to be sure it is clean and well-tinned.

For this experiment, you will use the tube socket on your circuit board and the terminals on your chassis. You will mount the circuit board along the edge of the chassis and connect "jumper" wires from the tube socket terminals in the copper foil to the 7-lug terminal strip on the chassis.

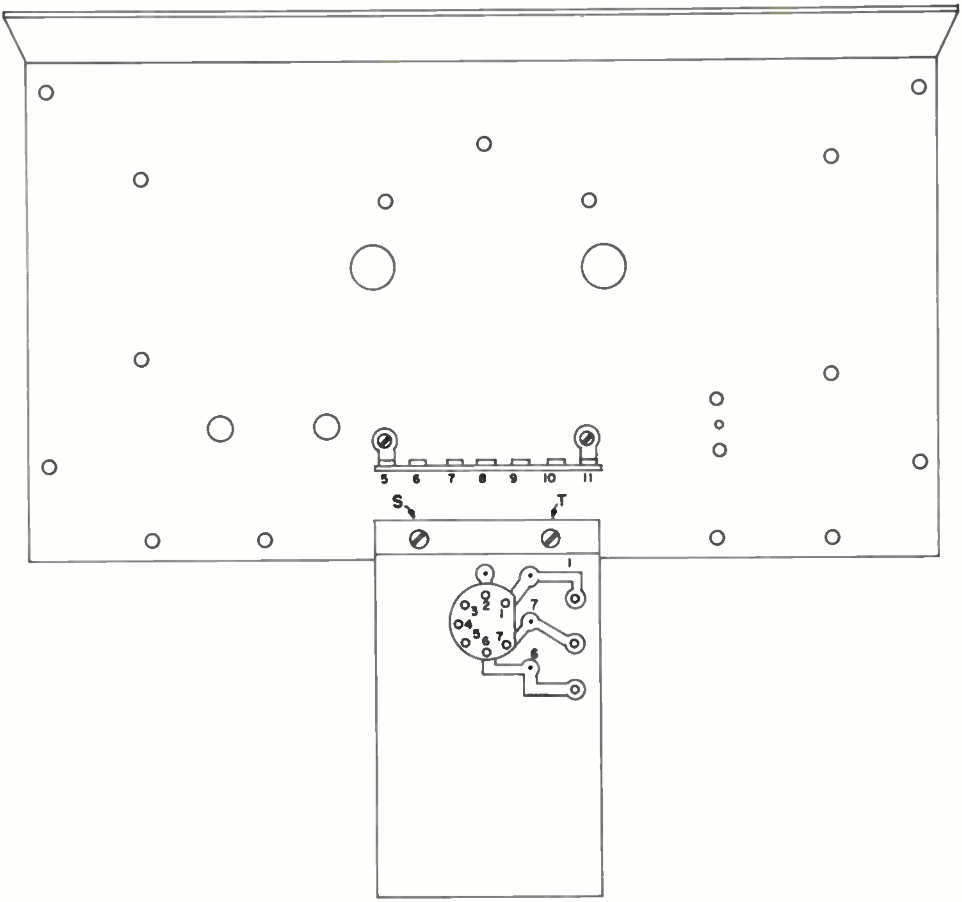

Fig. 4-2. Mounting the circuit board on the experimental chassis.

Mount the circuit board over holes S and T in the chassis (the holes are identified in Fig. 11 and Fig. 4-2). Position the circuit board over the edge of the chassis as shown in Fig. 4-2. Note that the tube socket is toward the chassis and the foil side of the board is turned upward. Attach the board with 1/4" X 4-40 screws through the mounting holes in the circuit board and chassis. Attach two 4-40 nuts and tighten.

The pins on the tube socket or tube are numbered from the blank space in a counterclockwise direction when viewed from the top. As shown in Fig. 4-3, pin 1 is at the right of the blank space, pin 2 is next, and so on. Pin 7 is to the left of the blank space. The pin in the center of the socket is not numbered. We will be primarily interested in pins 1, 6, and 7 of the socket. Connections to these holes are labeled on the foil side of EC24.

Refer to Fig. 4-4 as you make the following connections. Connect a short length of hookup wire from the hole in the foil which connects to pin 1 of the tube socket to terminal 8 on the 7-lug terminal strip. Remove about 1/4" insula-

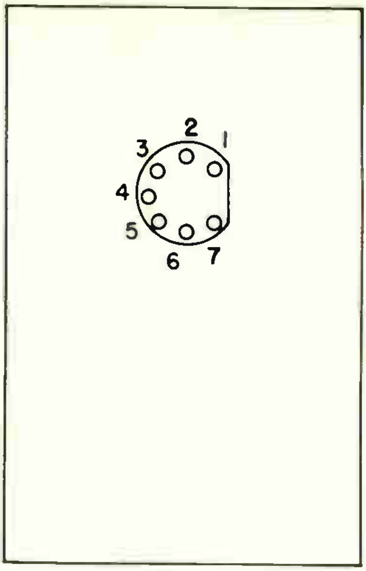

Fig. 4-3. Identifying the tube socket pins on the etched circuit board.

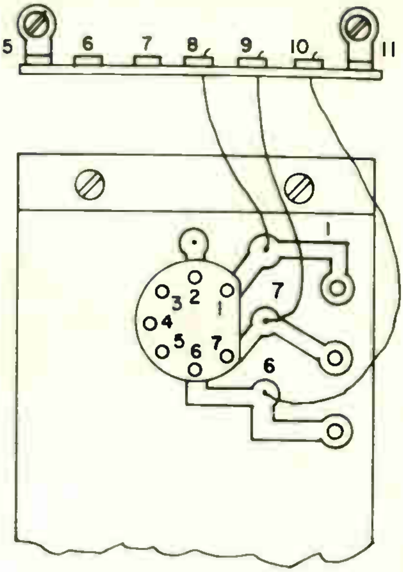

Fig. 4-4. Wiring connecting the tube socket to the terminal strip.

tion from each end of the wire. Slip the end of the wire through the hole in the circuit board from the foil side and solder to the foil.

Similarly, connect a short length of hookup wire from the hole in the foil at pin 7 to terminal 9.

In the same manner, connect a short length of hookup wire from the hole in the foil at pin 6 to terminal 10.

We often refer to a terminal or a conductor connected to a tube socket pin by the tube pin number or even by the element of the tube connected to that pin when a tube is inserted in the socket. Thus, the terminals on the chassis may be identified by the tube socket pin numbers, or as the grid, cathode and plate terminal of the 6C4 tube.

When working from schematic diagrams, remember that ground symbols indicate connections to the common return point (the chassis in this case) and that these connections can be made to anything that is connected to the chassis electrically. As your chassis is presently set up, you can use terminals 1, 5, 11, and 15 as ground connections.

If you are connecting two or more leads to a given point, do not solder until all leads are in position.

In this experiment, you are to wire a circuit directly from a schematic diagram. The diagram you are to use is shown in Fig. 4-5. The tube socket pins are indicated by the open circles nearest the tube symbol. All of the other terminals, which are shown by black dots, represent terminals on the terminal strip.

Before mounting a part, make a trial fit to determine where the part should be located. Sometimes this technique is used by experienced technicians in order to get a neat layout and prevent undue crowding of parts.

Step 1: To mount resistor R_1.

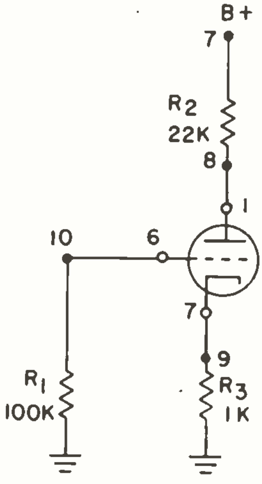

Fig. 4-5. Circuit used in Step 1.

First, find R_1 on the schematic diagram in Fig. 4-5. Notice that it is a 100,000-ohm resistor. Select a 100,000-ohm resistor from among the parts you have collected for this experiment.

From the schematic, you can see that R_1 is connected between pin 6 of the tube socket and ground. Because these connections will be made on the terminal strip, the connection will be made to terminal 10 and a ground terminal.

As stated earlier, there are four places where you can make your ground connection. The solder lug, terminal 1, and the mounting feet of the terminal strips, terminals 5, 11 and 15, are bolted directly to the chassis. Thus, they make electrical contact with the chassis and can be used for ground connections.

Connect one end of the 100,000-ohm resistor to terminal 10 and connect the other end to whichever ground point you find to be most convenient. Bend the resistor leads so that they do not touch the chassis. Also, they should not make contact with any other terminals. Solder terminal 10. Do not solder the ground terminal because you may want to make other connections to it.

Step 2: To mount resistor R_2.

Find resistor R_2 on the schematic diagram. You will see that it is a 22,000-ohm resistor (indicated by 22K on the diagram). You can also see that R_2 is connected from pin 1 of the tube socket, which is the same as terminal 8 on the terminal strip to terminal 7. Terminal 7 is marked "B+" on the schematic. Connect one lead of the 22,000-ohm resistor and solder these connections.

Step 3: To mount resistor R_3.

R_3 is a 1000-ohm resistor. On the schematic, R_3 is between pin 7 of the tube socket and ground.

Install the resistor between terminal 9 on the terminal strip (which is electrically the same as pin 7) and ground. You will have to choose a ground terminal. There are no more connections to be made. Thus, you can solder all connections which you have not yet soldered.

Step 4: To check your work.

After all wiring is in place, check your work against the schematic diagram. This check should now show:

1. A 100,000-ohm resistor between tube socket pin 6 and a ground terminal.
2. A 22,000-ohm resistor between tube socket pin 1 and terminal 7.
3. A 1000-ohm resistor between pin 7 of the tube socket and ground.

Discussion: In this experiment, you have gained experience in working from a schematic diagram. You have practiced reading resistor color codes, and you have again practiced making solder connections. You will use each of these skills every time you work on any electronic equipment.

After you have looked over your work to be sure that it is electrically equivalent to the circuit shown in Fig. 4-5, turn to the back of this manual. On page 77 you will see Fig. 4-6. This shows two ways in which you might have arranged your parts. However, these are not the only possible ways to mount the parts. As long as your arrangement is electrically the same as Fig. 4-5, you have done the experiment correctly.

Instructions For Statement No. 4: After carefully checking your work, answer the statement here and on your Report Sheet. Then unsolder the connections and remove the resistors. Disconnect the three jumper wires from the terminal strip and from the circuit board. Remove the circuit board from the chassis, clean the holes, and put the board aside. Finally, clean the resistor leads and terminals so that they will be ready for use in later experiments.

Statement No. 4: When I wired the circuit used in this experiment, I connected the 22,000-ohm resistor to the:

[✓ *(1) plate*]
(2) cathode
(3) grid

terminal of the tube socket.

Learning to Use A Meter

An electric current is invisible, odorless and tasteless. In other words, we cannot tell that a wire is carrying current unless we use some special means of detecting it.

Although a bell or light bulb can be used to show the presence of current, neither of these devices will indicate how much current is flowing. The current in the circuit must be at a certain level before the bell will ring or the bulb will light. For example, the light bulb will light to full brilliance when its greatest current is flowing through it. As the current is decreased, the light will grow dimmer. Finally, it will reach a point where the light will give no visual indication of current, even though current may still be present in the circuit. Something is needed that will show not only whether there is current flowing, but also how much current is flowing. A meter will do both of these jobs.

MEASURING CURRENT

A meter that is used to measure current is known as an ammeter. An ammeter indicates current in amperes. The ampere, however, is much too large a unit for most measurements in electronics, so we use a meter that indicates either milliamperes (ma) or microamperes (μa). A milliampere equals one-thousandth of an ampere and a microampere equals one-millionth of an ampere. Such meters are called milliammeters and microammeters. They are made the same and operate in the same manner as an ammeter. The only difference is that the milliammeter and microammeter are much more sensitive and will respond to much smaller currents.

The meter you will use in your experiments has a range of 0 to 200 microamperes. This means that a full scale reading on the meter indicates that 200 microamperes are flowing through the meter. When the meter pointer is at half scale, half of 200 microamperes or 100 microamperes are flowing through the meter. When the meter pointer is at 1/10th scale, 20 microamperes are flowing through the meter.

PREPARING THE METER

The meter supplied in this kit is an extremely delicate instrument. It contains a jewel movement similar to that of a fine watch. Therefore, the meter must be handled with care at all times. We cannot replace any meter that has been damaged through careless handling or improper usage. If you follow carefully the instructions given, you will have no trouble with the meter. However, if you fail to follow the instructions, you may damage your meter and have to replace it.

The meter case is plastic. It can easily be scratched with a screwdriver or similar tool, or by scraping it across your workbench. Also, the plastic can be permanently damaged by heat. Be sure that you do not accidentally touch the soldering iron to the meter case.

While you are performing these experiments, the meter will be left in its box. You will connect wires to the meter terminals so that you will have easy access to the meter.

You will need the following:

- 2 **Large solder lugs (LU7)**
- 1 **Meter (ME21)**
- 2 **Diodes (SR12)**
- **Hookup wire**
- **Solder**

Your meter is supplied with mounting hardware and two large nuts for each terminal. These parts are in an envelope in the meter box. Save all of the hardware as you will have need for it later.

To prepare the meter, place a soft pad or towel on your workbench. Next, remove the meter from the box and place the meter carefully on the pad or towel, face down, and with the top of the meter away from you.

Remove the wire from the meter terminals. The terminals were shorted together to prevent damage to the meter during shipment. If the meter is shaken or dropped, the physical movement will cause the meter pointer to move. A voltage is generated in the coil attached to the pointer. The short circuit across the meter terminals permits the current to flow through the terminals and back through the coil. This cancels the tendency of the coil to move and protects the meter from violent pointer swing.

You will now attach the large solder lugs to the meter terminals. First, attach a large nut to one of the terminals and run it all the way down. Then slip a large solder lug over the terminal and secure it with another nut. Position the solder lug so it points toward the bottom of the meter case and tighten the nut. Hold the lower nut with a small wrench or pliers and tighten the outer nut. Do not allow the terminal to turn, since this could damage the connection inside the meter case.

In a similar manner, attach two nuts and a solder lug to the other meter terminal and tighten the nuts.

Now you will identify the lugs on the back of the meter. The one on the left as you face the back of the meter is the positive, or plus terminal of the meter; the one on the right is the negative or minus terminal. The terminals may be further identified by plus or minus signs stamped on the plastic or on the ends of the screws or "POS" and "NEG" printed near the terminals.

Examine the two diodes supplied with this kit. Refer to Fig. 3-3 to help you identify the cathode leads.

Connect the lead at the cathode end of one diode to the positive terminal of the meter. This is diode D_1 in Fig. 34. Slip the end of the lead through the lug attached to the terminal. Do not solder at this time. Slip the anode lead of D_1 through the negative terminal lug.

Connect the second diode, D_2, to the meter terminals also, but with the opposite polarity. Slip the cathode lead through the negative terminal lug and the anode lead through the positive terminal lug. Do not solder at this time.

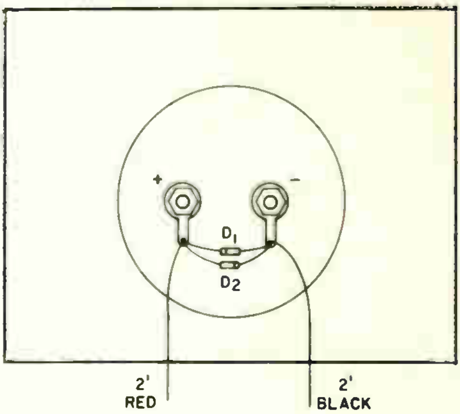

Fig. 34. Connections to the meter movement.

Prepare 2-foot lengths of red and black hookup wire. Remove about 1/4" of insulation from each end of each wire.

Connect the 2-foot length of red hookup wire to the positive meter terminal lug. Check to see that all three leads are through the hole in the terminal; then solder the connection. Be sure all three leads are soldered. After the solder cools, test the connection.

In a similar manner, connect and solder the length of black hookup wire to the negative meter terminal lug. Compare your wiring with Fig. 34 to see that you have done the work correctly.

Next, you will connect the meter leads to terminals on your chassis. Refer to Fig. 35. Connect the red lead from the meter to terminal 14. Connect the black lead from the meter to terminal 12.

Connect a 6" length of hookup wire from terminal 14 to terminal 10. Solder terminal 14.

In order to simplify the instructions, we will call terminal 10 the "positive meter terminal" and we will call terminal 12 the "negative meter terminal."

Put the meter in its box, face up. Do not attempt to make any measurements with your meter until instructed to do so.

The diodes, which you connected to the meter, are used to help protect the meter movement from excessive current. When a voltage of about .6 volt is present, one of the diodes will conduct and provide a low resistance path around the meter movement. We use two diodes connected with the opposite polarities to provide protection regardless of the polarity of the excessive voltage.

In normal operation, the voltage across the meter terminals will not exceed .15 volt. Therefore, the diodes have no significant effect on the operation of the meter unless excessive voltage is applied.

SETTING THE METER POINTER TO ZERO

The meter pointer should rest directly

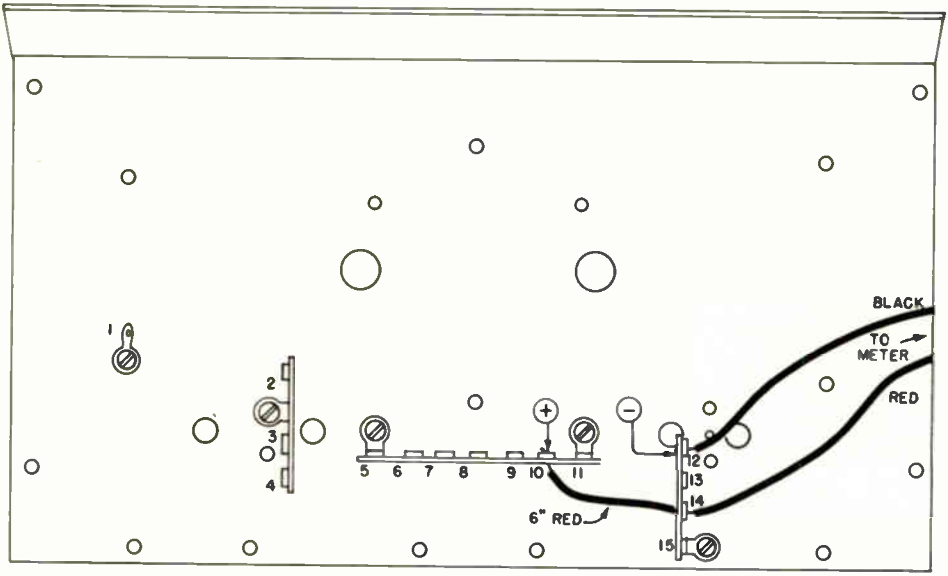

Fig. 35. The meter leads connected to terminals 12 and 14 with a jumper from 10 to 14.

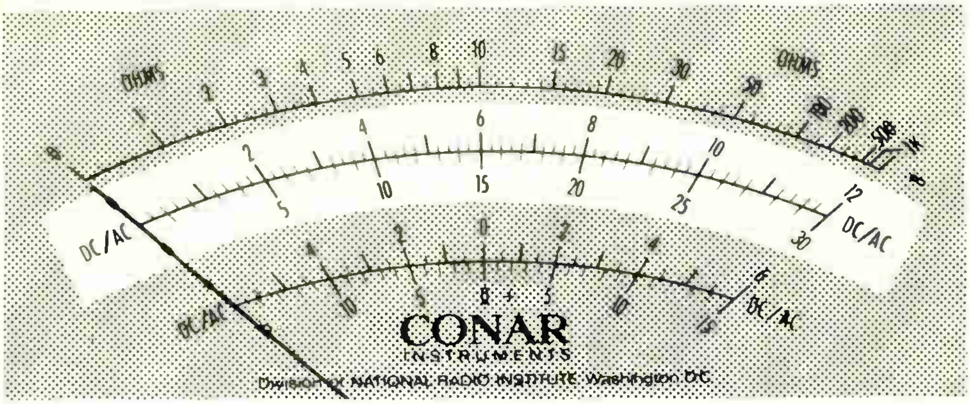

Fig. 36. The 0-12 and 0-30 volt scales on your meter.

over zero as shown in Fig. 36 when the meter is not in use. To set the pointer to zero, use a screwdriver blade that fits in the plastic screw slot on the meter face. Too small or too large a blade can damage the screw. Turn this screw, and notice that the meter pointer can be placed to the right or to the left of zero. Leave the screw adjusted so the meter pointer is over the zero mark. It is unlikely that you will have to make this adjustment again.

READING THE METER

The first time you look at the face of the meter you received in this kit, you may think that the meter is complicated and that it will be difficult to read. As a matter of fact, it is no more difficult to read a meter than it is to tell time on a clock. Of course, a meter may be something new to you, and it will take some practice to learn how to read it quickly. However, it will not be long before you will be able to read it at a glance.

At this time we will concentrate on the 0 to 12 and 0 to 30 volt scales. As you will see, the two scales may often be used together to help you obtain precise readings. These two scales are shown in white in Fig. 36. The 0 to 12 volt scale is the upper scale and has the numbers 0, 2, 4, 6, 8, 10 and 12 printed in black. The 0 to 30 volt scale is the lower scale and has the

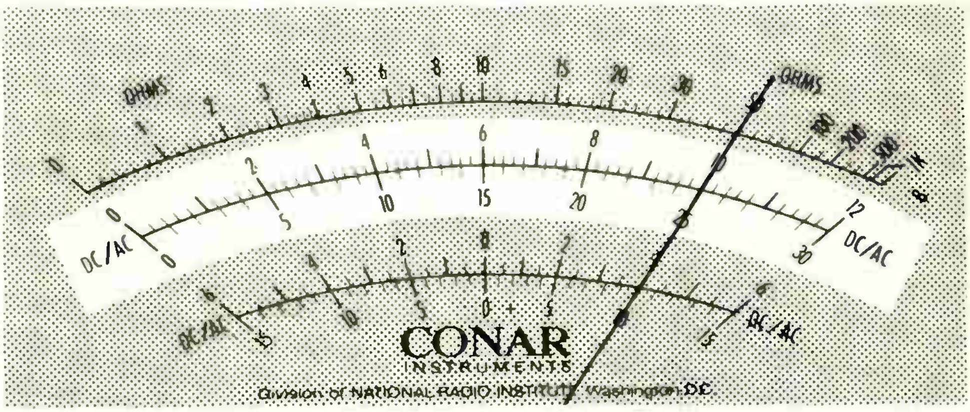

Fig. 37. A meter reading of 25 or 10.

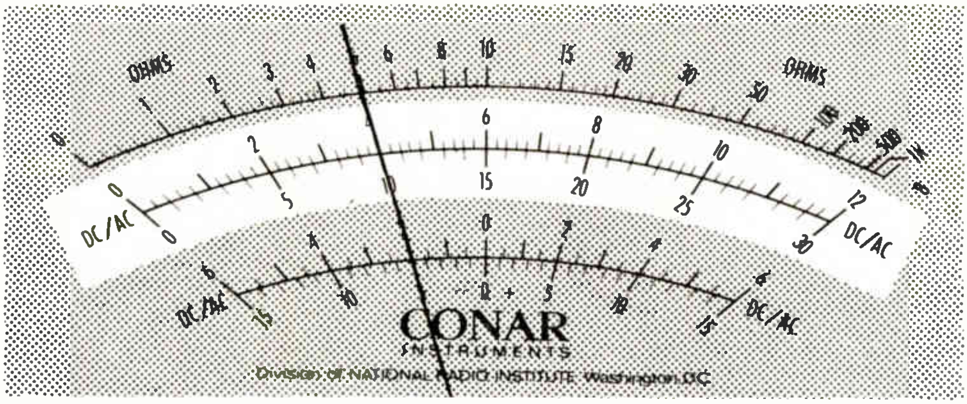

Fig. 38. A meter reading of 10 or 4.

numbers 0, 5, 10, 15, 20, 25 and 30 printed in black. Notice that the 0 to 12 volt scale has several short marks as well as some longer unnumbered marks. The 0 to 30 volt scale has four short unnumbered marks between each number.

Now look at the meter shown in Fig. 37. In this case the pointer is indicating 10 on the 0 to 12 volt scale and shows 25 on the 0 to 30 volt scale. If the pointer is as shown in Fig. 38, the reading would be 10 on the 0 to 30 volt scale and 4 on the 0 to 12 volt scale. These readings are quite easy to determine, as you can see, but what happens if the pointer is somewhere between the numbers on the scale?

Look at the scale shown in Fig. 39. Now the pointer is over one of the short marks of the 0 to 12 volt scale, but is between two short marks on the 0 to 30 volt scale! To read this value, note that on the 0 to 12 volt scale there are nine marks (or ten spaces) between 6 and 8; eight short marks and one long mark. The long mark represents 7 volts, and each short mark represents 0.2V. The pointer in Fig. 39 is on the third short mark following the 6 volt mark. Since each short mark is 0.2V, the pointer shows a reading of 6.6 volts.

Now, what is the reading of Fig. 39 on the 0 to 30 volt scale? First, notice that

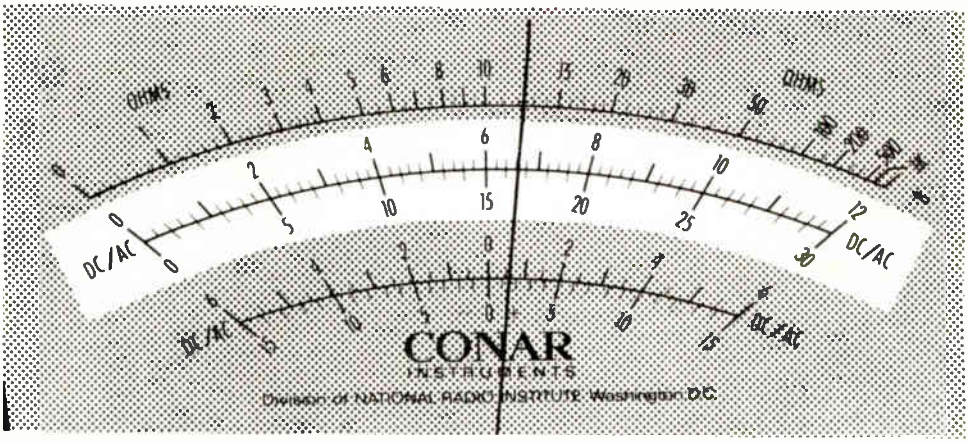

Fig. 39. Another sample meter reading.

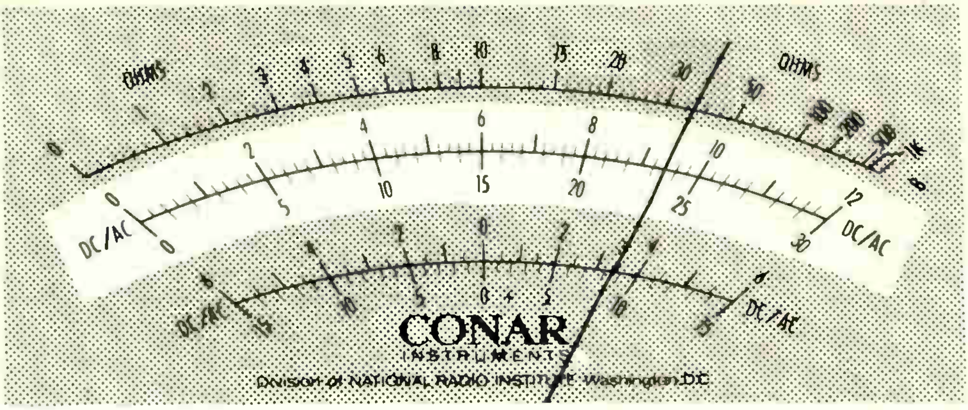

Fig. 40. Study this meter reading and see if you can tell what it is.

between 15 and 20 there are four short marks. Each mark, therefore, represents one volt. The pointer is halfway between the first and second marks following 15 so the reading is 16.5 volts. You can tell that the pointer is exactly halfway between the two marks by looking at the upper (0 to 12 volt) scale. On this scale, every other mark falls exactly halfway between the one volt marks on the 0 to 30 volt scale. This means that while the 0 to 30 volt scale is marked in one volt steps, you can determine readings to one half a volt by looking at the divisions on the 0 to 12 volt scale.

Let's look at another example. Take a look at the scale shown in Fig. 40. Using the reasoning that we applied in the previous examples, can you tell what the reading would be on the 0 to 12 and 0 to 30 volt scales? If you have trouble, go back and reread the material in the previous paragraphs. After careful study you should have no difficulty in seeing that the readings are 9.4 volts and 23.5 volts respectively on the 0 to 12 and 0 to 30 volt scales.

There is always the possibility that the pointer will not fall precisely on one of the short marks of the 0 to 12 volt scale. How are these values read? Take a look at Fig. 41. Notice here that the pointer is halfway between the second and third short marks after 4 on the 0 to 12 volt

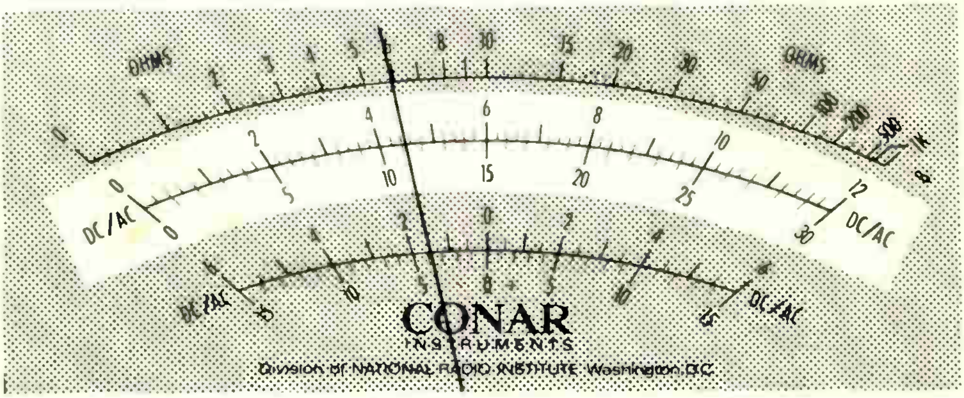

Fig. 41. Here is another meter reading for you to practice on.

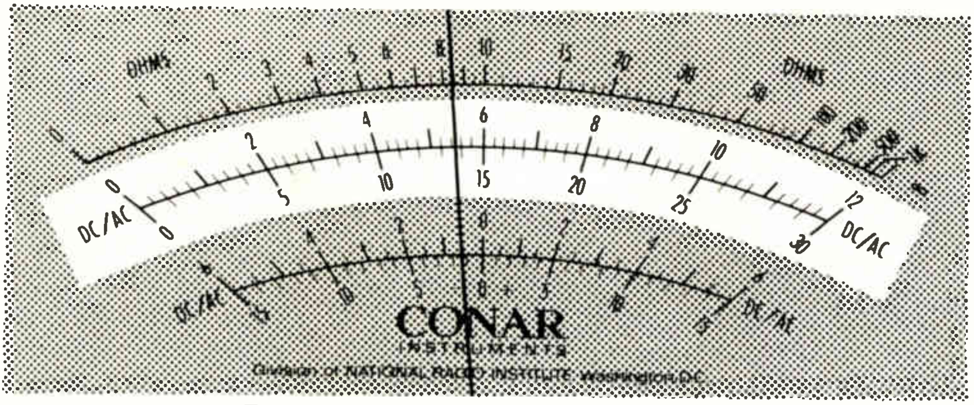

Fig. 42. What is the indication on this meter?

scale. This would be a reading of 4.5 volts. On the 0 to 30 volt scale it is just as easy. The pointer falls one fourth of the way between the first and second mark after 10, so the reading is 11.25 volts.

As a final example, try your hand at reading the two values indicated in Fig. 42. Again, the pointer does not fall on any of the scale marks of either scale. Let us see how close we can come to reading the meter by applying what we have already learned. On the 0 to 12 volt scale, the pointer is between 5 and 6. We can be more exact than that; it appears to be halfway between the second and third marks following the (unmarked) 5 volt mark. The first mark is 5.2 volts, the second mark is 5.4 volts and the third mark is 5.6 volts. Therefore the reading is between 5.4 and 5.6 volts. How much, is the question. The pointer falls about halfway between 5.4 and 5.6 volts so we would call it 5.5 volts. There is, of course, some uncertainty in this reading. For the purposes of your experiments, you would read it as 5.5 volts.

What reading does Fig. 42 represent on the 0 to 30 volt scale? Well, it is somewhere between 10 and 15 volts. Each short mark represents one volt, so the reading would be between 13 and 14 volts. Remember that the short mark on the *upper* scale (0 to 12 volts) is exactly halfway between the 13 and 14 volt marks, or in other words represents 13.5 volts. The pointer falls to the right of this mark so the reading must be between 13.5 and 14.0 volts. We would probably call this 13.75 volts; any value from 13.7 to 13.8 volts would be sufficient.

Building A Simple Series Circuit

You have already studied Ohm's Law and you know that there is a definite relationship between the voltage, current and resistance in a circuit. In Experiment 5, you will see just what happens to the current when you change either the resistance in the circuit or the voltage applied to the circuit. Before you begin Experiment 5 you will prepare the chassis by installing some parts on it. Then, when you begin Experiment 5 you will add some more parts and perform the Experiment.

In addition to your meter and chassis, you will need:

- 2 4.7K-ohm resistors (yellow-violet-red-silver)
- 1 6.8K-ohm resistor (blue-gray-red-silver)
- 1 1.5-volt flashlight cell
- Black hookup wire
- Red hookup wire
- Solder

Inspect the tip of your soldering iron. If necessary, file and retin the tip.

You will connect the three resistors to terminals 7, 8, 9 and 10 on your chassis. The chassis with the resistors in place is shown in Fig. 43. Begin by connecting one lead of a 4.7K-ohm resistor to terminal 10. (There should already be a red wire connected to terminal 10.) Temporarily solder the lead and the red wire to terminal 10. Bend the resistor leads near the body of the resistor and push the free lead through the slot in terminal 9. Connect one lead of another 4.7K-ohm resistor to terminal 9. Solder terminal 9. Connect the other lead of this resistor to terminal 8. Connect one lead of the 6.8K-ohm resistor from terminal 8 to terminal 7 as shown in Fig. 43. Solder terminal 8.

Remove 1/4" of insulation from each end of a 10" length of red hookup wire. Connect and solder one end to terminal 7. Leave the other end free.

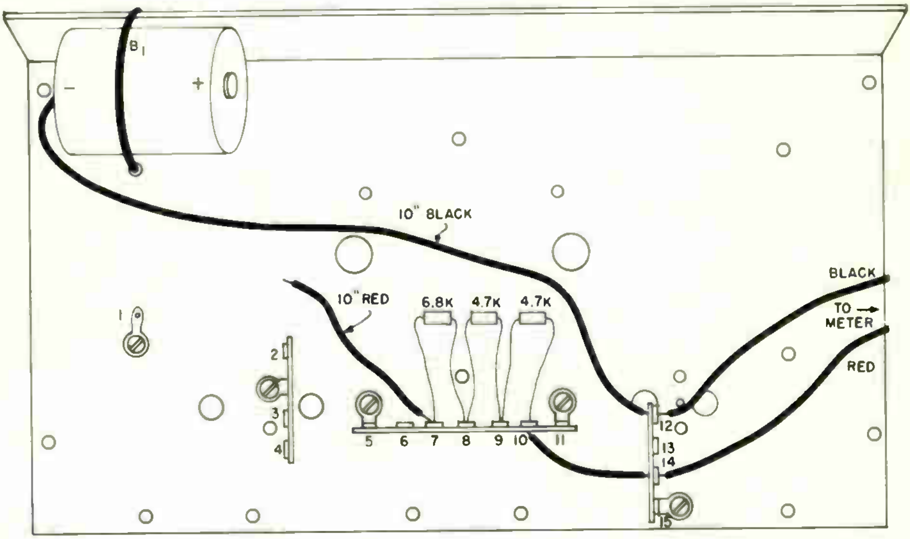

Fig. 43. Experimental chassis wired for Experiment 5.

Fig. 44. How to clean the center of the bottom of a flashlight cell with a piece of sandpaper.

You should now have three series-connected resistors going from the positive meter terminal (terminal 10) to terminal 7. The total resistance between terminal 7 and the positive meter terminal is the sum of the values of the three resistors; a total of about 16,000 ohms.

You now have a 0-200 microampere meter with approximately 16,000 ohms in series with it.

In order to measure current, your meter must be connected to a source of voltage with the proper polarity. The positive terminal of the voltage source must always be connected to the lead or circuit point that goes to the positive meter terminal.

At first, we will use a flashlight cell which produces 1.5 volts dc as a source of voltage. To do this, you are to connect a wire from the negative meter terminal, terminal 12, to the negative battery terminal. Notice that one end of your flashlight cell has a raised portion while the other end is flat. The negative battery terminal is the end with no raised section. Clean a spot in the middle of the bottom of the cell with a piece of fine sandpaper, as shown in Fig. 44.

Be sure that your soldering iron tip is clean and hot. Then, hold the end of your roll of solder on the negative terminal of the cell and touch your soldering iron to the solder. Rub the iron around so that the terminal becomes well-tinned.

Now cut a 10" length of black hookup wire and remove 1/4" of insulation from each end. Place one end of the 10" length black hookup wire on the tinned area of the negative terminal of the cell. Touch the tip of your soldering iron to the wire and the tinned portion of the cell. The solder should melt and run over the wire. Remove the heat and allow the joint to cool. If the solder does not flow smoothly over the wire, add a little more solder as you heat the connection.

If you like, you can use a piece of hookup wire to secure the cell in place along the bend in the chassis as shown in Fig. 43. Note that the negative terminal is toward the left side of the chassis.

Fig. 45. Schematic symbol for a battery.

The symbol we use on schematic diagrams to represent a battery is shown in Fig. 45. Each pair of lines represents one cell of the battery. The short wide line represents the negative terminal and the longer thin line represents the positive terminal. To represent one cell, we use only one pair of lines; but to represent several cells, we do not try to show the exact number, as two or more pairs are sufficient.

EXPERIMENT 5

Purpose: To show that current flowing in a series circuit will change when the

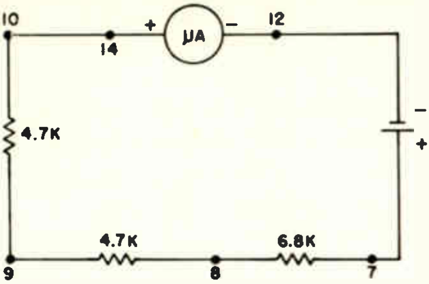

Fig. 5-1. The circuit you will use in Step 1 of Experiment 5.

resistance in the circuit or the voltage applied to the circuit is changed.

Introductory Discussion: Although the circuit you will use in this experiment is a simple circuit, it will act in the same way that a more complex circuit would act when either the resistance or voltage is changed.

This experiment will demonstrate Ohm's Law, which is one of the most important laws you will study. Do each step of the experiment carefully and make sure you understand exactly what you are doing and what the changes in current that you observe mean.

Experimental Procedure: In this experiment, in addition to the meter, chassis and the circuit you have just wired, you will need the following:

1 1.5-volt flashlight cell
Hookup wire

The first circuit you will use is shown in Fig. 5-1. When you read the meter, use the 30-volt scale which you practiced reading previously.

Step 1: To connect 1.5 volts across the meter and series resistor combination.

Touch the red wire from terminal 7 to the positive terminal of the flashlight cell. This closes the circuit and causes current to flow.

Observe the pointer on your meter. It should be slightly below one-half scale. If you get no reading, look for a bad connection or a short circuit. Check to be sure that your circuit is wired as shown in Fig. 5-1. Trace the wiring from terminals 12 and 10 back to the terminals on the meter. Also check for a short circuit between the meter terminals or leads.

The meter scale which you are using in this experiment (Fig. 5-2) is the 0 to 30 volt scale. However, in this experiment you are using this scale only as a relative indication of the amount of current in the circuit. The meter indicates a current of about 100 microamperes, since you know that a full scale reading (30) repre-

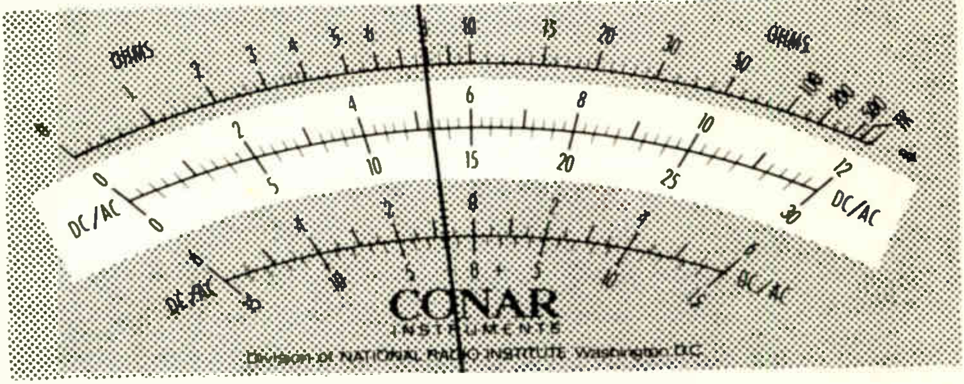

Fig. 5-2. The meter reading of Step 1 should be approximately 13 on the 0-30 scale.

STEP	READING
1	14.3
2	29.5
3	23.9

Fig. 5-3. Record your reading for Experiment 5 here.

sents a current of 200 microamperes.

In later experiments you will learn that the 0 to 30 volt scale will also be used to indicate 0 to 3 volts, and 0 to 300 volts. The 0 to 12 volt scale will also be used to indicate ranges of 0 to 1.2 volts, 0 to 120 volts and 0 to 1200 volts. For the time being, however, you need only be concerned with relative scale indications on the 0 to 30 volt scale. Read the meter carefully and write the reading of the meter in the space provided for Step 1 in Fig. 5-3. Remove the red wire from the positive terminal of the flashlight cell to open the circuit.

Step 2: To determine the effect of increasing the voltage in a series circuit.

To do this, you will connect another flashlight cell in series with the cell you used in Step 1. This is shown in the schematic diagram in Fig. 5-4.

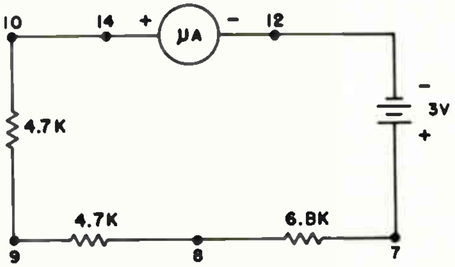

Fig. 5-4. Circuit to use for Step 2.

Clean the positive terminal of the second flashlight cell with a piece of fine sandpaper. Hold your soldering iron on the terminal and apply solder. Melt

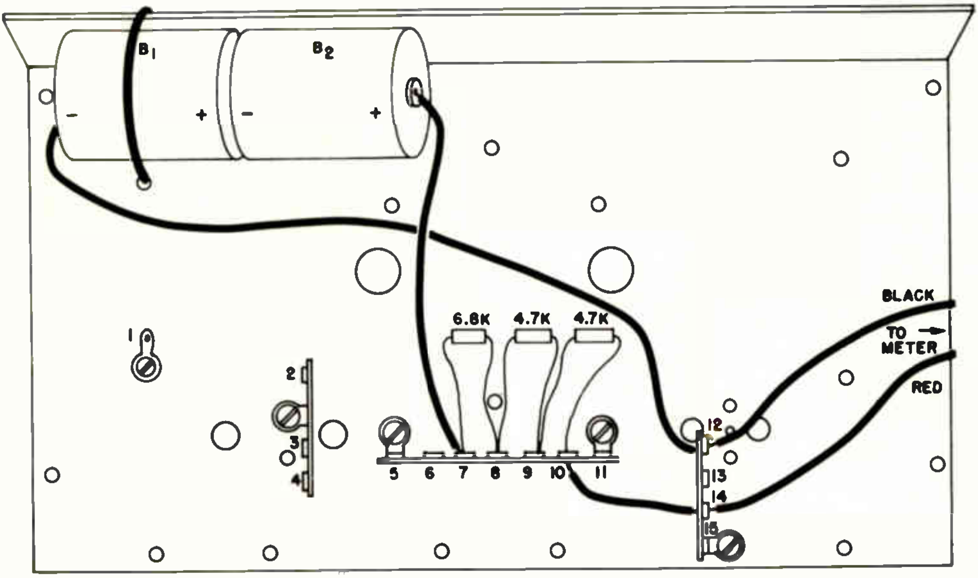

Fig. 5-5. Series resistor with 3-volt battery.

enough solder on the terminal to tin it. Rub the tip of the iron around so that the terminal is well-tinned.

Place the free end of the red wire connected to terminal 7 on the tinned area of the positive terminal of this flashlight cell and apply heat to solder the wire to the terminal. Use additional solder if necessary.

Now, to complete the circuit, hold the positive end of the first flashlight cell against the negative terminal of the second flashlight cell, as shown in Fig. 5-5. This places the two 1.5-volt cells in series, thus forming a 3-volt battery.

The meter pointer should swing to the right to just under 30 on the 30-volt scale. Look at the meter carefully, read the value as closely as you can, and write the reading in the space reserved in Fig. 5-3.

Step 3: To show that the amount of current will change when the resistance is changed.

The circuit you will use is shown in Fig. 5-6. Unsolder the red wire from the positive terminal of the second flashlight cell and from terminal 7 and set the cell to one side. Solder one end of the red wire you just removed to terminal 8.

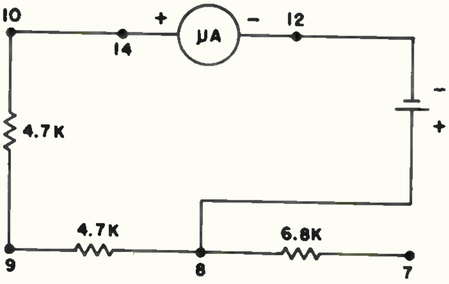

Fig. 5-6. Circuit you use for Step 3.

Touch the free end of the red wire to the positive terminal of the flashlight cell on the chassis. You now have a total of about 9,400 ohms in the circuit with a source voltage of 1.5 volts. Read the meter and record your readings in the space for Step 3 in Fig. 5-3.

Discussion: In this experiment, you have seen what happens in a series circuit when the voltage or resistance is changed. You should have a reading of something less than 15 for Step 1. When you doubled the voltage in the circuit by adding a second flashlight cell, you should have obtained a reading of about two times the original reading. In other words, when you double the voltage supplied to the circuit, the current in the circuit doubles. From this, you can see that there is a definite relationship between voltage and current in a series circuit.

In Step 3, when you reduced the resistance in the circuit, you should have found that the current was greater than in Step 1. This shows that if you reduce the resistance in a series circuit, the current will increase. We could have shown that increasing the resistance will cause the current to decrease, but this should have been obvious from the steps that you have already carried out in this experiment.

Instructions For Statement No. 5: In order to complete this statement you must obtain one additional reading. You will find the current through a resistance of approximately 7,500 ohms connected across a voltage of 1.5 volts. To get this reading, wire the circuit shown in the schematic in Fig. 5-7. Connect a short length of hookup wire from terminal 7 to terminal 9. Solder both connections. Fig.

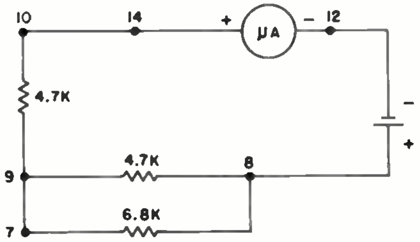

Fig. 5-7. Connect the free end of the resistors to the junction of the first and second resistors to get Statement answers.

5-8 shows the chassis wired according to Fig. 5-7. This places a 4,700-ohm resistor in parallel with the 6,800-ohm resistor. This combination is in series with the other 4,700-ohm resistor. Next, touch the red wire from terminal 8 to the positive terminal of the flashlight cell on the chassis.

Observe the meter reading on the 30-volt scale and answer the statement.

Remove the three resistors connected to terminals 7, 8, 9 and 10 and clean their leads so they will be ready for reuse. Also, disconnect and remove the short length of wire connecting terminals 7 and 9 and remove the 10″ length of red wire from terminal 8. Do not discard this wire as you can reuse it in later experiments. Do not remove any of the other wires.

Statement No. 5: When I touched the free end of the lead from terminal 8 to the 1.5-volt cell, I obtained a reading of approximately

(1) 15
[✓ *(2) 30*]
(3) 10

EXPERIMENT 6

Purpose: To show how to connect resistors in parallel; and to show that the net resistance of a group of parallel-connected resistors is less than that of the smallest resistor in the group.

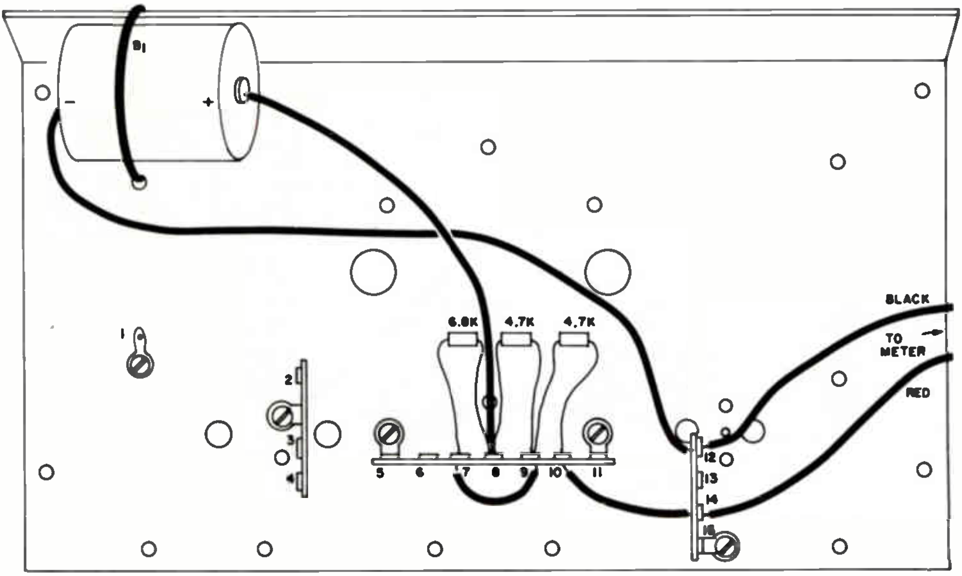

Fig. 5-8. Chassis arrangement for Statement 5.

Introductory Discussion: In the last experiment, you learned how to connect resistors in series with a source of voltage. When resistors or any other parts are connected across a voltage source, they are called a load. In a circuit of this type, each resistance, including that of the meter, can be considered as part of the total load resistance. Thus, the total load resistance is the sum of the individual resistances.

In this experiment we will show that loads can also be connected to the source voltage so that the entire source voltage is connected to each load. We will also show that when loads are connected in this manner, the net resistance of the combined load is less than the resistance of the smallest resistance in the group.

Experimental Procedure: In making these tests, you will use the following parts:

2 100,000-ohm resistors
1 82,000-ohm resistor
2 Flashlight cells
Red hookup wire

Since good connections will be required, we will solder leads to the batteries. To do this, clean the battery terminals (that you have not yet used) with a piece of sandpaper and tin them, as you learned to do in the last experiment.

Remove 1/2" of insulation from each end of an 8" length of red hookup wire. Place one end of one wire on the tinned area of the positive terminal of the cell connected to terminal 12. Touch the soldering iron to the junction. The solder on the tinned areas should melt and run over the wire. If necessary, add solder to get a good connection. Remove the heat, and let the joint cool. Solder the other end of the wire lead to the tinned area on

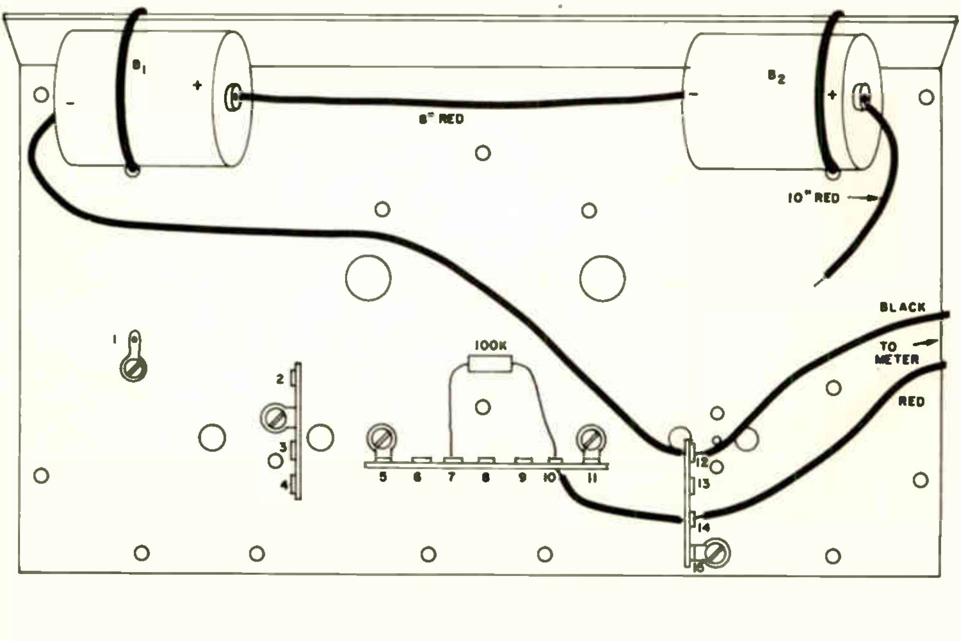

Fig. 6-1. Chassis wired for Step 1.

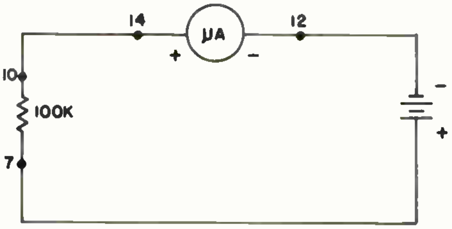

Fig. 6-2. Schematic diagram for Step 1.

the negative terminal of the second battery.

Secure the second battery to the right side of the chassis as shown in Fig. 6-1. You can pass a piece of string or hookup wire through the hole in the chassis and around the battery.

We will call the cell on the left side of the chassis B_1 and we will call the cell on the right B_2.

Locate the 10″ length of red hookup wire you used in the last experiment. Solder one end of this wire to the positive terminal of the flashlight cell, B_2. Leave the other end free.

You now have a 3-volt battery. The negative terminal of the 3-volt battery is the negative terminal of B_1 and is connected to terminal 12. The red wire connected to the positive terminal of B_2 is the "positive battery lead."

Complete the circuit shown in Figs. 6-1 and 6-2 by soldering a 100,000-ohm resistor between terminals 7 and 10.

Step 1: To get an indication of the current flowing with a 100,000-ohm resistor in the circuit.

Touch the free end of the positive battery lead, which is soldered to the positive terminal of B_2, to terminal 7. Read the meter indication on the 30-volt scale. The meter pointer should be in about the position shown in Fig. 6-3. Your reading may be somewhat higher or lower than the value shown in Fig. 6-3 because of normal tolerances in resistor values and the output voltages of different cells. Read the meter carefully and then remove the free end of the positive battery lead from terminal 7 to open the circuit. Record your reading in the space provided for Step 1 in Fig. 6-4.

Step 2: To connect a 100,000-ohm resistor in parallel with the resistor used in Step 1.

Clean the leads of the second 100,000-ohm resistor and connect it in parallel with the resistor used in the last

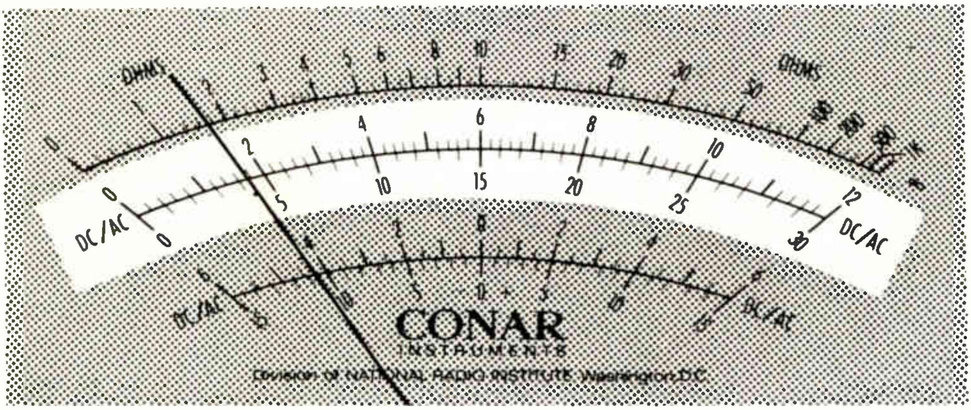

Fig. 6-3. Meter reading for Step 1.

STEP	READING
1	4.5
2	9.25
3	14.75

Fig. 6-4. Record your reading for Experiment 6 here.

step. You may solder the leads to terminal 7 and 10 or, if you prefer, you may solder the leads to the leads of the resistor already in the circuit. The circuit for this step is shown in Fig. 6-5.

Touch the positive battery lead to terminal 7 and read the meter on the 30-volt scale. Remove the positive battery lead after recording your reading in the chart in Fig. 6-4.

Step 3: To add an 82,000-ohm resistor to the parallel connected 100,000-ohm resistor.

Clean the leads of the 82,000-ohm resistor and solder it either to terminals 7 and 10 or to the leads of one of the resistors used in Step 2. The schematic diagram of the circuit for this step is shown in Fig. 6-6. Touch the positive battery lead to terminal 7 and note the reading on the meter. Open the connection after recording your reading in Fig. 6-4.

Discussion: In this experiment you have demonstrated what happens to the current in a circuit when resistors are connected in parallel. You should have discovered that as you added the second 100,000-ohm resistor to the circuit, your reading on the meter was about twice what it was with only one resistor in the circuit. When you added the third resistor, you should have found that the current increased still more.

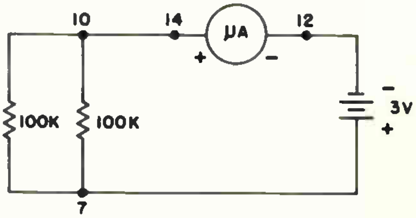

Fig. 6-5. Schematic diagram for Step 2.

You know from Ohm's Law that the amount of current that will flow in a circuit depends on the voltage applied to the circuit and the resistance in the circuit. In other words, I = E ÷ R. The value of E did not change; it was 3 volts throughout the entire experiment. Therefore, the change in current must have been entirely due to the change in resistance. In fact, the total resistance in the circuit decreased as you added more

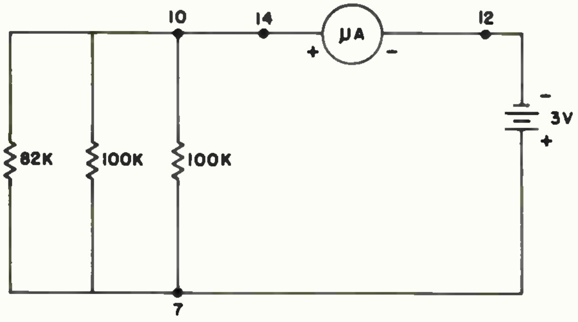

Fig. 6-6. Schematic diagram for Step 3.

resistors in parallel to produce the increase in the circuit current.

Of the three resistors used in this experiment, the 82,000-ohm resistor has the lowest resistance, and we will use this resistor by itself in the statement for this experiment.

Instructions for Statement No. 6: Remove all three resistors from terminals 7 and 10. Separate the resistors and reconnect the 82,000-ohm resistor to terminals 7 and 10.

Touch the positive battery lead to terminal 7 and note the reading on the
5,75 meter. Open the circuit, and write the reading in the margin of this page. Answer the statement, and then disconnect the 82,000-ohm resistor. Clean and straighten its leads so that it will be ready for re-use. Leave all other connections alone as they will be used in the next experiment. Leave the two flashlight cells connected together and the lead from the negative terminal of the battery connected to terminal 12.

Statement No. 6: When I connected an 82,000-ohm resistor in place of the parallel group, the reading was:

~~*(1) higher*~~
[✓ *(2) lower*]

than the reading obtained in Step 3.

This indicates that the resistance of the parallel group was:

[✓ *(1) more than*]
(2) less than

that of the 82,000-ohm resistor by itself.

EXPERIMENT 7

Purpose: To show that the current is the same at every point in a series circuit.

Introductory Discussion: You already know that current in a circuit is the flow of electrons through the circuit. Electrons flow from the negative terminal of the voltage source, which is the battery in this experiment, through the load, and back to the positive terminal of the battery. Inside the battery, electrons flow from the positive terminal to the negative terminal.

In any series circuit, the current is the same throughout the entire circuit. In other words, if you connect a current-measuring instrument into the circuit to measure the current, it will not make any difference where you connect the instrument -- you will always get the same current reading. In this experiment you will demonstrate this. You will even show that the current flowing in the battery itself is the same as the current flowing in the external circuit.

Experimental Procedure: In this experiment, in addition to the meter, chassis and flashlight cells you will need the following parts:

1 100,000-ohm resistor
1 82,000-ohm resistor
1 22,000-ohm resistor
Hookup wire

Fig. 7-1 shows the circuit you will use for Step 1. This is the same setup used in

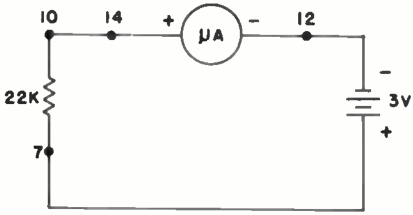

Fig. 7-1. Schematic of circuit for Step 1.

STEP	READING
1	20.5
2	20.5
3	20.25

Fig. 7-2. Record your reading for Experiment 7 here.

the last experiment. To construct the circuit, solder the leads of the 22,000-ohm resistor to terminals 7 and 10. When you have made these connections you should have:

(1) a wire from the negative battery terminal (negative terminal of B_1) to terminal 12,
(2) a wire connecting terminal 14 and terminal 10,
(3) a 22,000-ohm resistor connected from terminal 10 to terminal 7,
(4) a wire from the positive terminal of B_1 to the negative terminal of B_2, and
(5) a wire soldered to the positive battery terminal with the other end free. There should be no wire soldered to terminal 7.

If your circuit is properly wired, you may proceed with the first step.

Step 1: To measure the current leaving the battery.

Touch the free end of the positive battery lead to terminal 7. Read the meter on the 30-volt scale and record the reading in the space provided for Step 1 in Fig. 7-2. On the schematic in Fig. 7-1, you can see that the battery current flows from the negative battery terminal, through the meter to the resistor. It then flows through the resistor and back to the positive battery terminal.

Step 2: To measure the current returning to the battery.

Rewire the circuit as shown in Fig. 7-3. To do this, first unsolder and remove the red wire from terminal 10 to terminal 14. Unsolder the black negative battery lead from terminal 12. Solder the free end of the black wire to terminal 10. Connect and solder a length of hookup wire from terminal 7 to terminal 12.

Notice on the schematic in Fig. 7-3 that the meter is now between the resistor and the positive battery terminal.

Touch the free end of the positive battery lead to terminal 14 to complete the circuit. Read the meter on the 30-volt scale. Open the circuit after recording the reading for Step 2 in Fig. 7-2.

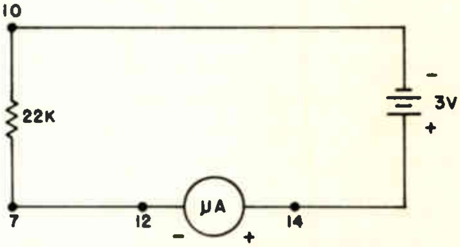

Fig. 7-3. Circuit for Step 2.

Step 3: To show that the current flowing inside the battery itself is the same as the current flowing in the external circuit.

The battery you are using in this experiment consists of two flashlight cells. Large batteries of the type used in earlier tube-type portable radios have voltages of 45 and 90 volts and are made up of groups of 1.5-volt cells, similar to flashlight cells. These are connected in series to get the required voltage. The more cells that are connected in series, the higher the voltage.

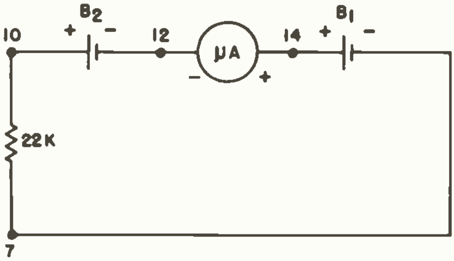

Fig. 7-4. Circuit for Step 3.

With an external circuit connected to the battery, you can measure the internal current in the battery by inserting a meter between any two adjacent cells.

To illustrate this in the experiment, wire the circuit shown in the schematic in Fig. 7-4. Fig. 7-5 shows a pictorial diagram of the wiring. Unsolder and remove the short length of hookup wire connected from terminal 7 to terminal 12.

Locate the wire connecting the two flashlight cells. Unsolder this wire from the positive terminal of B_1. Solder the free end of the wire to terminal 12.

Solder the negative battery lead to terminal 7.

Connect and solder a length of hookup wire from terminal 14 to the positive terminal of B_1. Check to see that your circuit is wired correctly.

Touch the positive battery lead (from B_2) to terminal 10 to complete the circuit. Read the meter carefully and open the circuit after recording your reading in the space provided for Step 3 in Fig. 7-2.

Discussion: In Step 3 of this experiment, the circuit is connected as shown in Fig. 7-4. Here the meter is actually placed between the two flashlight cells, and is measuring the current flowing from one cell into the second cell. Compare your readings for this step with your readings in Steps 1 and 2.

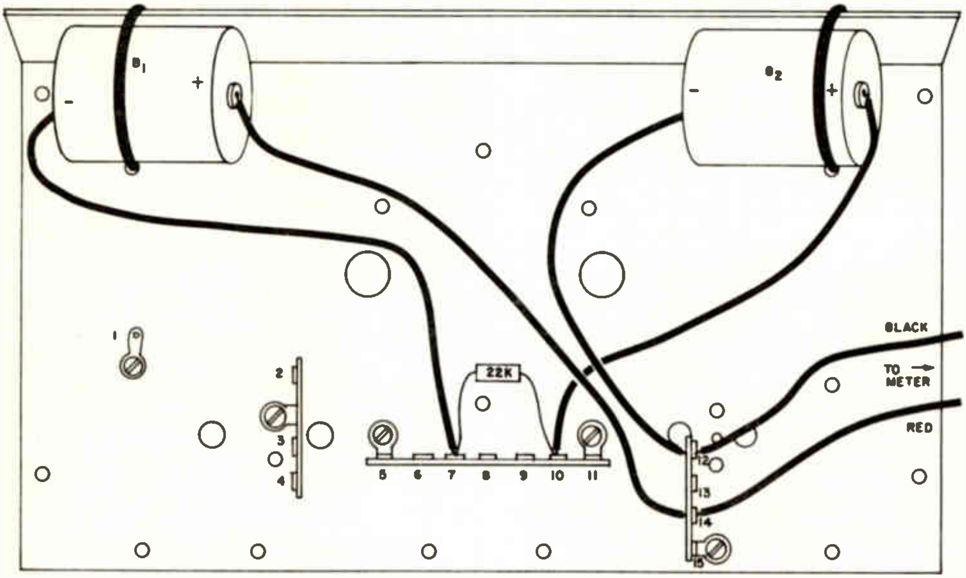

Fig. 7-5. Chassis wired for Step 3.

Notice that the readings are the same in all three steps. This demonstrates an extremely important fact. The value of the current is the same throughout the entire circuit. This means you can connect a meter at any point in a simple series circuit to measure the current; the reading will be the same regardless of where the meter is connected.

It is easy to see why the current in a series circuit is the same throughout the entire circuit. When you close the circuit by touching the battery wire to the circuit, electrons begin to leave the negative terminal of the battery. They strike other electrons and cause them to move. These electrons, in turn, strike additional electrons, and so on throughout the entire circuit. This, of course, occurs instantaneously; as soon as the circuit is completed, electrons start moving through the entire circuit.

At the same instant that electrons begin to leave the negative terminal of the battery, pushing other electrons before them, other electrons begin entering the positive terminal of the battery, because the electrons are attracted by the positive potential. The number of electrons moving in one part of the series circuit is exactly equal to the number of electrons moving in any other part of the series circuit.

Instructions for Statement No. 7: In the preceding experiment, you demonstrated that when resistors are connected in parallel, the total resistance of the combination is lowered. If the applied voltage does not change, this results in an increase in current. For this Report Statement, you will connect a low resistance in series with a high resistance. Then you will shunt each resistance with an 82,000-ohm resistor and note the effect on the total circuit current.

To carry out the experiment for this statement, you will need one 100,000-ohm resistor and one 82,000-ohm resistor. Wire the circuit as shown in Fig. 7-6. Connect a 100,000-ohm resistor from terminal 10 to terminal 13. Solder both connections. Check your circuit to see that it is wired according to Fig. 7-6. Solder the positive battery wire to terminal 13.

Note the reading on the meter on the 30-volt scale. Bend the leads of the 1.8 82,000-ohm resistor so that you can conveniently bridge the resistor across either the 100,000-ohm or the 22,000-ohm resistor. Bridge the 82,000-ohm resistor 2 first across the 100,000-ohm resistor and note the meter reading on the 4 margin. Next move the 82,000-ohm resistor over and bridge the 22,000-ohm resistor. Again, read the meter and note the reading in the margin.

Compare the two meter readings and answer the Report Statement.

Unsolder the positive battery lead from terminal 13. Unsolder and remove the 100,000-ohm resistor connected between terminals 10 and 13 and the 22,000-ohm resistor connected between terminals 7 and 10. Unsolder and remove the short red wire between the positive terminal of B_1 and terminal 14. Unsolder the red wire from terminal 12. (The other end of

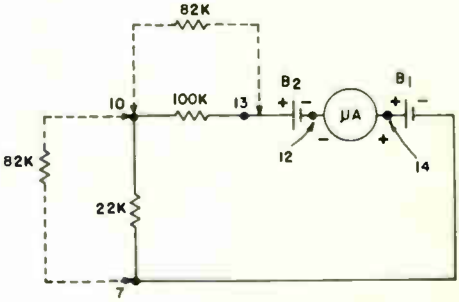

Fig. 7-6. Circuit for Statement 7.

this wire is soldered to the negative terminal of B_2.) Solder the free end of this wire to the positive terminal of B_1 to connect the two cells in series again. Clean and straighten the leads of the resistors you removed and clean all unused terminals.

Statement No. 7: When I shunted the 100K-ohm resistor with an 82K-ohm resistor, and then shunted the 22K-ohm resistor with the 82K-ohm resistor, I found that the effect on the current was:

(1) greater when the 22K-ohm resistor was shunted.
(2) greater when the 100K-ohm resistor was shunted.
(3) the same in both cases.

EXPERIMENT 8

Purpose: To show that the total current flowing in a parallel circuit is the sum of the currents flowing in the branches.

Introductory Discussion: In any piece of electronic equipment, there are usually several tubes or transistors connected across a single power supply. Each circuit, or stage, as they are usually called, generally draws a different current. The total current that the power supply must provide is equal to the sum of the currents drawn by the individual stages. Each stage acts as a separate load connected across the power supply. If a defect develops in one stage so that the stage draws more current than it should, not only will that stage be overloaded, but also the total current that the power supply must furnish will increase. As a result, the power supply may be overloaded. It is important for you to remember this when you start doing repair work. If a power transformer overheats, it does not necessarily indicate that the transformer is defective; it often indicates

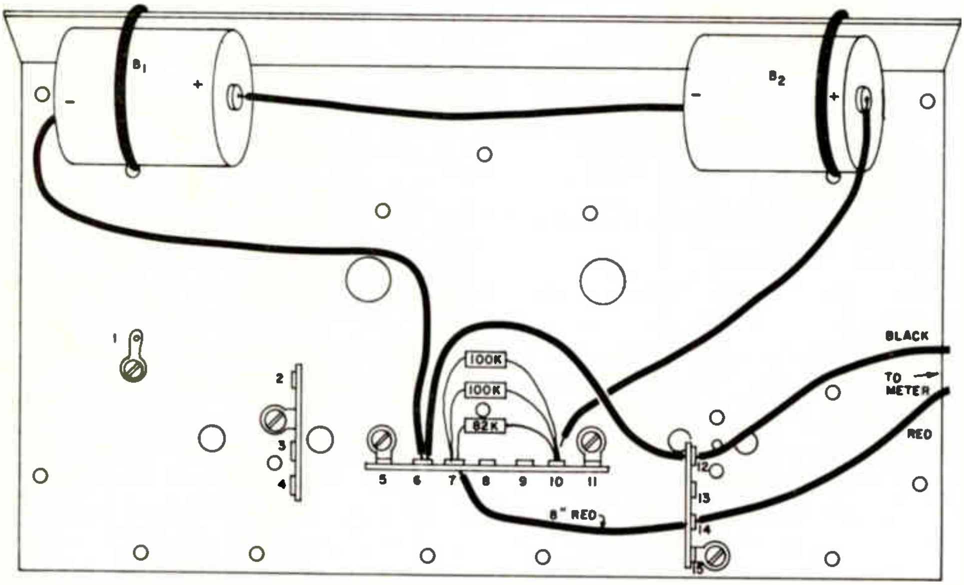

Fig. 8-1. Chassis for Step 1.

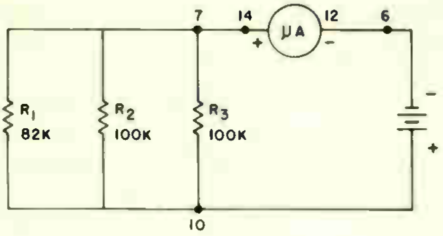

Fig. 8-2. Schematic of circuit for Step 1.

that a defect in some stage other than the power supply is causing the transformer to overheat.

In this experiment you will prove that the sum of the individual branch currents in a parallel circuit is equal to the total circuit current.

Experimental Procedure: In addition to the parts already on the experimental chassis you will need the following parts:

2 100K-ohm resistors
1 82K-ohm resistor
Hookup wire

You should have the two flashlight cells connected to form a 3-volt battery on your chassis. For this experiment, you must wire your circuit as shown in Figs. 8-1 and 8-2.

Solder the two 100,000-ohm resistors and the 82,000-ohm resistor to terminals 10 and 7. You should then have two 100,000-ohm resistors and the 82,000-ohm resistor connected in parallel. Connect the black wire from the negative terminal of B_1 to terminal 6. Next strip 1/4" of insulation from each end of a 5" length of black hookup wire and solder this wire to terminals 6 and 12 as indicated in Fig. 8-1.

Remove about 1/4" of insulation from each end of an 8" length of red hookup wire. Solder one end to terminal 14 and solder the other end to terminal 7. Do not connect the positive battery lead at this time.

Before you go to Step 1, carefully check your work with the schematic of Fig. 8-2 and the pictorial drawing of Fig. 8-1. Make sure you have made all of the connections correctly.

Step 1: To measure the total current flow in a parallel circuit.

Touch the positive battery lead (connected to the positive terminal of B_2) to terminal 10. Observe the readings on the 30-volt scale on your meter. Remove the positive battery lead from terminal 10 after recording your reading in the space provided for Step 1 in Fig. 8-3.

STEP	READING
1	14.6
2	4.60
3	5.00
4	5.75

15.35

Fig. 8-3. Record your reading for Experiment 8 here.

With the arrangement shown in Fig. 8-2, the three resistors are in parallel and the current which you measured is the total current flowing in the circuit.

Step 2: To measure the current through a 100,000-ohm resistor.

You will use the circuit shown in the schematic diagram in Fig. 8-4. To change your wiring to make this circuit, unsolder the lead of the 82,000-ohm resistor and the lead of one 100,000-ohm resistor from terminal 7. Solder these two leads to terminal 6.

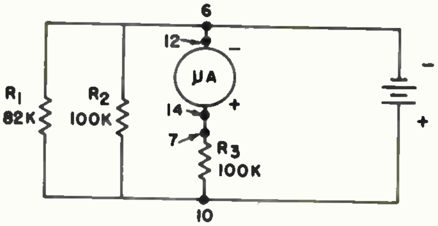

Fig. 8-4. Circuit for Step 2.

As you can see in the schematic, when the circuit is completed, current will flow through all three resistors. However, only the current through R_3 the 100,000-ohm resistor connected to terminal 7 will flow through the meter.

Touch the positive battery lead to terminal 10. Read the meter on the 30-volt scale and record your reading for Step 2 in Fig. 8-3.

Step 3: To measure the current through the second 100,000-ohm resistor, R_2.

Fig. 8-5 shows the circuit. To make the necessary changes, unsolder the 100,000-ohm resistor lead from terminal 7 and resolder it to terminal 6. Then unsolder the lead of the other 100,000-ohm resistor from terminal 6 and resolder it to terminal 7.

Touch the positive battery lead to terminal 10 and observe the meter indication on the 30-volt scale. Remove the battery lead from terminal 10 after recording your reading in the space for Step 3 in Fig. 8-3.

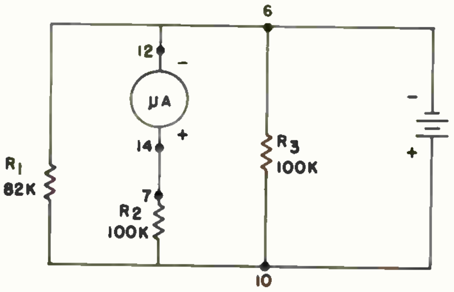

Fig. 8-5. Circuit for Step 3.

Step 4: To measure the current through the 82,000-ohm resistor.

Modify the circuit as shown in the schematic in Fig. 8-6. Unsolder the 100,000-ohm resistor lead from terminal 7 and resolder it to terminal 6. Unsolder the lead of the 82,000-ohm resistor from terminal 6 and resolder it to terminal 7. This places the meter in the 82,000-ohm resistor circuit only.

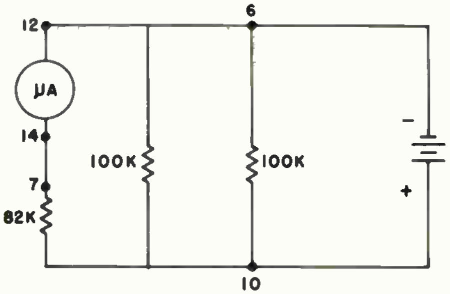

Fig. 8-6. Circuit for measuring the current through the 82K-ohm resistor.

Touch the positive battery lead to terminal 10. Read the meter on the 30-volt scale. Remove the positive battery lead from terminal 10 after recording your reading in the space provided for Step 4 in Fig. 8-3.

Discussion: In this experiment, you have measured the total current flowing in a circuit, and also the current flowing in the individual branch circuits. Since you used two 100,000-ohm resistors, you should have found that the current flowing through these resistors was the same.

In other words, the readings you obtained in Steps 2 and 3 should have been equal.

In actually taking this measurement, you may have found a slight variation because the resistors have a tolerance of 10%. Even though we call the resistor a 100K-ohm resistor, its actual resistance may be as much as 10,000 ohms more or less than 100,000 ohms. The resistance in series with the meter, therefore, may be any value between 90,000 and 110,000 ohms, which would account for the variation in your measurements. The 82,000-ohm resistor can have any value between 73,800 ohms and 90,200 ohms. Therefore, it is actually possible to have little or no difference in reading between the 82,000-ohm resistor and one or both of the 100,000-ohm resistors. In most electronics work, resistor values are not critical, and it is much more economical to use a resistor having a 10% tolerance, than it is to use a resistor having a 1% tolerance.

To show that the total current flowing in the circuit is equal to that in the individual branch circuits, add your readings for Steps 2, 3, and 4, and compare the result with the readings for Step 1. The sum of the readings recorded in Steps 2, 3, and 4 should be approximately equal to the reading you have recorded in Step 1.

Instructions for Statement No. 8: For this Statement, you do not need to take any additional measurements. You can use the readings you took in the experiment to answer the statement.

Answer the statement and unsolder and remove the two 100,000-ohm resistors and the 82,000-ohm resistor from terminals 6, 7, and 10. Remove the red wire from terminals 7 and 14 and remove the black wire from terminals 6 and 12.

Statement No. 8: When I measured the individual branch currents flowing in the circuit consisting of two 100K-ohm resistors and one 82K-ohm resistor, I found that the current was greatest

(1) through one of the 100K-ohm resistors.
[✓ (2)] through the 82K-ohm resistor.

This shows that maximum current will flow through the branch in the parallel circuit having

[✓ (1)] the lowest resistance.
(2) the highest resistance.

EXPERIMENT 9

Purpose: To show that a microammeter can be used as a voltmeter if a suitable resistor is placed in series with the meter.

Introductory Discussion: You have seen how a microammeter can be used to indicate the presence of current and to show if the current increases, decreases, or remains constant when circuit conditions are changed. We have not been able to measure the current in microamperes or milliamperes because the meter is not calibrated to read in microamperes. It would be possible to calculate the current from your scale readings, but since we are not interested in exact values, it is not necessary.

Your meter is a 0-200 microammeter. This means that a current of 200 microamperes must flow through the meter to give a full-scale deflection. In other words, when the pointer is at 30 on the 30-volt scale, the current flowing through the meter is 200 microamperes. (Microamperes is abbreviated μa.)

If your meter had a 200 microampere (200 μa) scale printed on it, and we inserted a resistance in series with the meter, and then connected the combination across a voltage source, you could read the current through the meter. The current would depend upon two things: the voltage of the source, and the resistance we placed in series with the meter. If we knew what the resistance was, we could read the current from the meter, and then calculate the voltage by using Ohm's Law. Ohm's Law states that $E = I \times R$. So we would multiply the current in amperes by the resistance in ohms to get the voltage of the source.

This arrangement has one drawback, however. It takes quite a bit of time to make the mathematical calculations. Actually, it is not necessary to do this, because as long as the resistance remains unchanged, the current will depend only on the voltage. Therefore, we can calibrate the meter to read directly in voltage. Now let us see how we can find out what resistor we need in order to use the 3-volt range on the meter.

To do this, we again turn to Ohm's Law. One form of Ohm's Law states that the resistance is equal to the amount of voltage divided by the amount of current. In other words, $R = E \div I$. We want the meter to read full scale when the voltage applied is 3 volts; therefore E will be equal to 3. We know that the meter is a 200 microampere meter; it takes 200 microamperes (200 μa) of current to make the meter read full scale. Converting this value to amperes, we get .0002 ampere. Now, to get the value of resistance needed, we divide 3 by .0002. This will give us 15,000. Therefore, the resistance value that should be added to the circuit is 15,000 ohms.

If we want to build an accurate meter, we will have to subtract the resistance of the meter itself from the resistance to be placed in series with the meter. However, the resistance of your microammeter is small compared to 15,000 ohms, so we will simply connect the 15,000-ohm resistor in series with the meter to give us a voltmeter that will read 3 volts on full scale. The error introduced by disregarding the meter resistance will be unimportant in this experiment.

As mentioned earlier, the scales on the meter are labeled 0 to 12 and 0 to 30. For the 3-volt scale, read the 0 to 30 volt scale but mentally divide the reading by 10, or place a decimal point before the last digit. For example, for a full scale reading, the pointer will point to 30. Dividing this by 10 gives us 3.0. Similarly, a reading of 20 is actually 2.0 on the 3-volt scale, just as 15 is 1.5 volts, 5 is 0.5 volts and so on.

Experimental Procedure: In this experiment, in addition to your meter and chassis with parts mounted, you will need the following parts:

1 15,000-ohm resistor
Hookup wire

Prepare 1′ lengths of red and black hookup wire. Remove about 1/2″ of insulation from each end of the wires.

Step 1: To convert your microammeter to a voltmeter.

Unsolder the red meter lead from terminal 14 and reconnect to terminal 13. Connect the 15,000-ohm resistor from terminal 13 to terminal 14. Solder terminal 13. Solder one end of the 1′ length of red wire to terminal 14. Leave the other end free.

Solder one end of the 1′ length of black hookup wire to terminal 12. The meter can now be used as a 0 to 3 volt voltmeter. The black wire connected to terminal 12 is your *negative voltmeter lead* and the red wire connected to terminal 14 is your *positive voltmeter lead.*

Step 2: To measure the voltage of the two flashlight cells connected in series.

The cells should still be connected in series as they were in the last experiment. Touch the negative meter lead (the black wire connected to terminal 12) to the negative terminal of the 3-volt battery, and touch the positive meter lead to the positive terminal of the 3-volt battery. Fig. 9-1 shows the circuit used in this step. Note the reading on the 3-volt scale on your meter. The reading should be approximately full scale, indicating a voltage of about 3 volts. The reading might be a little higher or lower than full scale, depending upon the tolerance of the 15,000-ohm resistor and the actual voltage of your battery. In general, new flashlight cells have a terminal voltage of 1.55 volts which drops to about 1.5 volts when the cells are heavily loaded (are supplying large current). In this circuit there is hardly any load so the battery voltage should be 2 times 1.55 volts or about 3.1 volts which would make your meter read slightly above full scale.

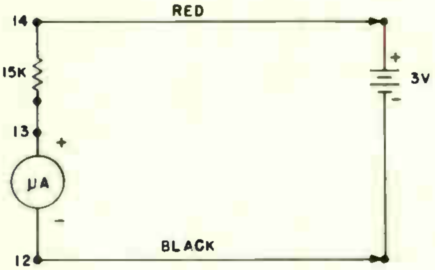

Fig. 9-1. Circuit to measure battery voltage.

Step 3: To measure the voltage of a single flashlight cell.

Touch the positive voltmeter lead to the positive terminal of one cell, and touch the negative meter lead to the negative terminal of the same flashlight cell. Note the reading on the meter. The reading should be about center scale, indicating a voltage of approximately 1.5 volts. Check the voltage of the other flashlight cell in the same way.

Discussion: The meter that you constructed in this experiment is often referred to as a 5,000-ohms per volt voltmeter. We usually write this as 5,000 ohms/volt. Notice that to convert the meter to a 3-volt voltmeter, we use a 15,000-ohm resistor. If we wanted to convert the meter to a 12-volt meter, we would have used a 60,000-ohm resistor. If we wanted to convert the meter to a 30-volt meter, we would have used a 150,000-ohm resistor. In all cases, to find the resistance needed, we multiply the required full scale voltage by 5,000.

In the early days of electronics, meters with sensitivities of 1,000 ohms/volt and 5000 ohms/volt were the only types available. Today most meters have sensitivities of 20,000 ohms/volt to 150,000 ohms/volt.

The sensitivity of the meter used in service work is important. If the meter has a sensitivity of only 5,000 ohms per volt, it is quite possible that you will not get an accurate indication of the voltage in a circuit. In the next experiment we will show you exactly how this can happen and why the sensitivity of the meter is important to the serviceman.

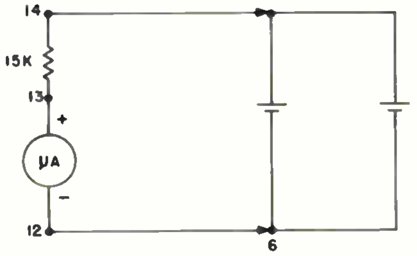

Fig. 9-2. Circuit for Statement 9.

Another type of meter, the vacuum tube voltmeter or the transistor voltmeter, has an even higher sensitivity than the meters previously discussed. For this reason most electronics technicians prefer this type to the simple voltmeter of the type you have just constructed. You will build a sensitive transistor voltmeter in the next Training Kit.

Instructions for Statement No. 9: In this statement, you are to measure the voltage of the two flashlight cells when they are connected in parallel. To do this, unsolder the red wire from the positive terminal of cell B_1 which is on the left side of your chassis. This wire should still be attached to the negative terminal of cell B_2. Solder the free end of this wire to terminal 6. Solder the free end of the positive battery lead (the wire soldered to the positive terminal of B_2) to the positive terminal of B_1. Check your work against Figs. 9-2 and 9-3.

Touch the positive voltmeter lead to the positive terminal of battery B_1 or B_2 and the negative meter lead to terminal 6. Note the reading on your meter, and answer the statement.

Unsolder the red wire from the positive terminal of battery B_1 and push the free end out of the way. Unsolder the red wire from terminal 6 and solder the free end to the positive terminal of flashlight cell B_1. Leave the 15,000-ohm resistor connected to terminals 13 and 14, and the

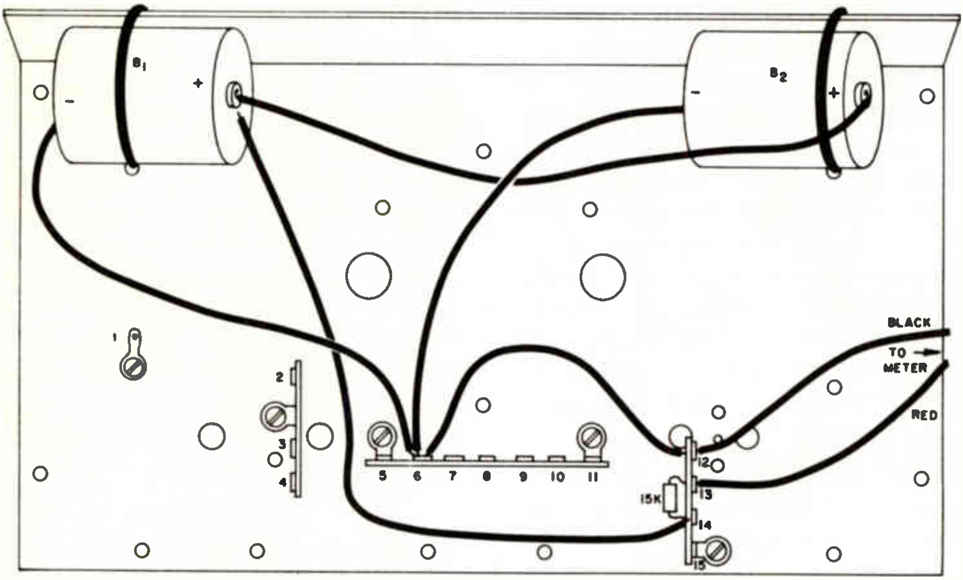

Fig. 9-3. Chassis used for Statement 9.

red and black voltmeter leads connected to terminals 12 and 13.

Statement No. 9: When I measured the voltage of the two parallel-connected flashlight cells, I found that it was approximately

(1) 3 volts.
[✓ *(2) 1.5 volts.*]
(3) 0.

EXPERIMENT 10

Purpose: To show that in a series circuit, there is a voltage across each part, that the sum of the voltages is equal to the source voltage, and that a voltmeter can upset the voltage division.

Introductory Discussion: You already know that if you connect your voltmeter across the battery, you get an indication of the voltage produced by the battery.

When the battery is connected to a series circuit, the battery voltage drives electrons through the circuit. The electrons, in moving through each part of the circuit, set up a voltage across each part. If you accurately measure the voltage across each part and add these voltages, you will find that the sum of these voltages is equal to the source voltage.

In this experiment, you will construct a simple circuit and measure the voltage across each of the individual parts in the circuit to prove that the sum of the voltages is equal to the battery voltage.

Experimental Procedure: In this experiment, in addition to the meter and chassis, you will need:

1 470-ohm resistor
1 680-ohm resistor
1 1,000-ohm resistor
2 100,000-ohm resistors
1 82,000-ohm resistor
2 Flashlight cells

Your flashlight cells should still be connected in series to form a 3-volt battery.

Construct the circuit shown in Fig. 10-1. Solder one lead of a 1,000-ohm resistor to terminal 6. Push the free lead through the slot in terminal 4. Connect the 680-ohm resistor between terminals 3 and 4 and solder terminal 4. Connect the 470-ohm resistor between terminals 2 and 3. Solder terminal 3. Solder the resistor lead and the free end of the positive battery lead to terminal 2.

Step 1: To measure voltages in a low-resistance series circuit.

You will use your 3-volt meter to measure the voltages in the circuit shown in Fig. 10-1.

To measure the source voltage, hold the negative voltmeter lead on terminal 6, and touch the positive meter lead to terminal 2. Observe the meter on the 3-volt scale and place your reading in the space for the source voltage in Fig. 10-2.

Next, while holding the negative voltmeter lead on terminal 6, touch the positive lead to terminal 4 and measure

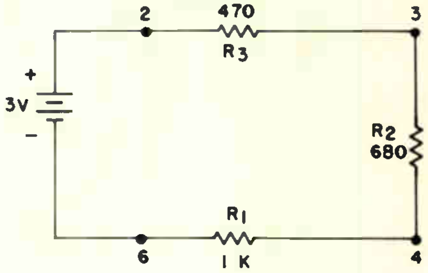

Fig. 10-1. Circuit for Experiment 10.

	READINGS
R_1	1.32V
R_2	.925V
R_3	.650V
$R_1+R_2+R_3$	2.895
SOURCE	3.1V

Fig. 10-2. Record your reading for Step 1 here.

the voltage across resistor R_1. Record this voltage in the space provided for R_1 in Fig. 10-2.

Move the positive meter lead to terminal 3 and the negative meter lead to terminal 4 and measure the voltage across resistor R_2. Record your reading in the space provided for R_2 in Fig. 10-2.

To measure the voltage across resistor R_3, touch the positive meter lead to terminal 2 and the negative meter lead to terminal 3. Read the voltage on the 3-volt scale on your meter and record your reading in the space provided for resistor R_3, in Fig. 10-2. Now add together the three voltages you recorded for R_1, R_2, and R_3 and put this value in place labeled $R_1 + R_2 + R_3$ in Fig. 10-2.

Unsolder the positive battery lead from terminal 2, to open the circuit. Unsolder and remove the 470-ohm, the 680-ohm and the 1,000-ohm resistors.

Step 2: To measure voltage in a higher resistance series circuit.

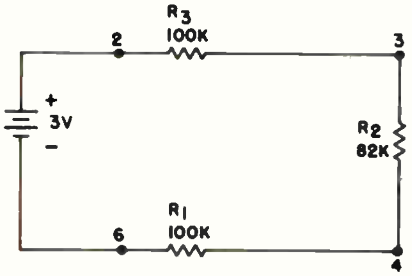

Fig. 10-3. Circuit used in Step 2.

Construct the circuit shown in Fig. 10-3. Solder one lead of a 100,000-ohm resistor, R_1, to terminal 6. Connect the other lead to terminal 4. Connect one lead of the 82,000-ohm resistor to terminal 4 and solder. Connect the other lead of this resistor to terminal 3. Connect and solder the other 100,000-ohm resistor, R_3, from terminal 3 to terminal 2. To complete the circuit, solder the positive battery lead to terminal 2.

Measure the voltage applied to the circuit by holding the positive voltmeter lead on terminal 2 and touching the negative voltmeter lead to terminal 6. Read your meter on the 3-volt scale and record your reading in the space reserved for the source voltage in Fig. 10-4.

	READINGS
R_1	.2 V
R_2	.2 V
R_3	.2 V
$R_1+R_2+R_3$	.6V
SOURCE	3.1V

Fig. 10-4. Record your readings for Step 2 here.

Using the same technique you used in Step 1, measure the voltages across each of the three resistors. Record these voltages in the spaces provided for it in Fig. 10-4. Now add together the three voltages you recorded for R_1, R_2, and R_3 and put this value in the place labeled $R_1 + R_2 + R_3$ in Fig. 10-4.

When you have made your readings, disconnect the positive battery lead from terminal 2.

Discussion: In Step 1, you measured the source voltage applied to the circuit and you measured the voltage across each resistor. You found that the source voltage was about 3 volts. This is the voltage across the three series-connected resistors.

The voltage drop across R_1 was about 1.4 volts, across R_2 it was about .95 volts and across R_3 about .7 volts. When you added the voltage drops across resistors R_1, R_2 and R_3, you should have found the sum to be approximately equal to the source voltage.

The voltage across a resistor is determined by the current in the resistor and the value or resistance of the resistor. As you would expect from Ohm's Law, the largest resistor has the largest voltage across it while the smallest resistor has the smallest voltage.

Another important point that you should learn from the experiment is how to connect the voltmeter to measure voltage. A voltmeter is always placed in parallel with or across the voltage you are interested in measuring.

To measure the battery voltage in the circuit in Fig. 10-1, you measure between terminals 2 and 6, which are directly across the battery. To measure the voltage across resistor R_1, you measure the voltage between terminals 4 and 6. In every case, the positive meter lead is connected to a more positive point than is the negative meter lead. The negative battery terminal is the most negative point in the circuit. In Fig. 10-1, the voltage at terminal 4 is more positive than the voltage at terminal 6. Similarly, the voltage at terminal 3 is more positive than the voltage at terminal 4 and the voltage at terminal 2 is more positive than the voltage at terminal 3.

You must always connect your voltmeter so the positive lead is connected to the more positive terminal. Otherwise, your meter will read backwards and may be damaged.

In Step 2, you also found that the supply voltage is about 3 volts. However, when you add the three readings taken for Step 2, you will find that the three voltage drops do not add up to 3 volts. At first glance, you might think that something is wrong.

Actually, the error is due to your meter resistance. The circuit you have when you connect the meter across R_1 is shown in Fig. 10-5.

Since the resistance of the voltmeter, which consists of the 15,000-ohm resistor and the resistance of the 0 to 200 microammeter, is only slightly more than

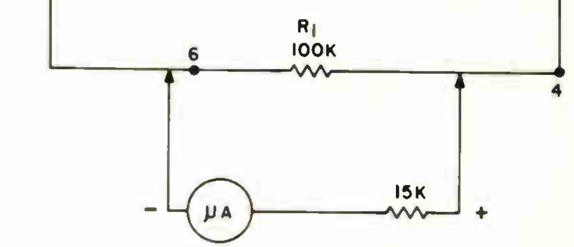

Fig. 10-5. Circuit for Experiment 10 with meter connected across R_1.

15,000 ohms, the total resistance of R_1 and the meter in parallel with it is much less than the 100,000-ohm value of R_1 alone. The resistance of the combination is very close to 15,000 ohms. Therefore, most of the voltage will be dropped across resistor R_2 and R_3, and very little will appear across the combination of R_1 and the meter circuit in parallel with it.

The same thing is true when you connect your meter across R_2 and R_3. Each time you connect the meter across a high resistance, the parallel combination of the meter and the resistor across which you are measuring voltage forms a resistance that is much lower than the original resistor value. The entire circuit, therefore, is upset and the voltage you measure is not the true voltage that is across the resistor when the meter is not connected to it.

To prevent such erroneous readings, you need a meter with a very high resistance. If your meter had a sensitivity of 100,000 ohms per volt on the 3-volt scale, you would have a total resistance of 300,000 ohms in the voltmeter circuit. Then, when you make your measurements, you would be placing 300,000 ohms in parallel with 100,000 ohms. Although the meter resistance is still low enough to upset the circuit you used in this experiment, it would not upset the circuit nearly as much as the 15,000-ohm resistance did.

The resistor values used in the first step were much less than the combined value of the meter and its series resistor. For this reason, the meter resistance has very little effect on the readings you made in the circuit in Step 1.

In your next set of experiments, you will build a transistorized voltmeter. This meter has a resistance of several megohms. Thus, when you use this meter to measure the voltage in high resistance circuits, you will get a more accurate voltage indication than you would using a simple voltmeter such as that which you used in this experiment.

Instructions for Statement 10: For this statement, you are to measure the voltage drop across two resistors. R_1 and R_2 in Fig. 10-3. Solder the positive battery lead to terminal 2. Touch your negative meter lead to terminal 6 and the positive meter lead to terminal 3. Observe your meter indication on the 3-volt scale and write the reading in the margin on this page.

Statement No. 10: When I measured the voltage across resistors R_1 and R_2, I found that the voltage was .44

[✓ *(1)*] *less than 1 volt.*
(2) approximately 1.5 volts.
(3) approximately 3 volts.

After you have answered the statement, unsolder the positive battery lead from terminal 2 and push it out of the way. Unsolder and remove the red and black meter leads and all other parts and wires connected to terminals 12, 13, and 14. Straighten and clean the leads of the 15,000-ohm resistor and set it aside.

You should still have the two flashlight cells connected in series and attached to the chassis. You should also have the two 100K-ohm and one 82K-ohm resistors soldered to terminals 2, 3, 4 and 6. These resistors and the 3 volt battery will be used in the first experiment of the next training kit.

Looking Ahead

This completes the experiments in Kit 1T. One of the most important things you should have learned is how to solder correctly. As we pointed out, you will make soldered connections in all your electronics work, and one poorly soldered connection can cause you hours of unnecessary work.

In later kits you will have further experience in reading the meter. Of course, you will use the meter throughout your Practical Demonstration Course. You should have learned how to read the 0 to 30 volt and 0 to 12 volt scales in this group of experiments; in the next kit, you will learn how to read the ohmmeter scale. You also demonstrated a number of important basic circuit actions. It is much easier to study and understand the more advanced circuits that you will encounter later if you understand how the simple circuits work, and what changes in the circuit will do to voltage distribution and current flowing in the circuit.

In the next kit, you will build a transistorized voltmeter (tvom). You will find this work extremely interesting, and at the same time you will be building an instrument that will be useful to you in the rest of your experiments, and later when you start work in any branch of the electronics field. In addition to building the tvom you will continue with your studies of basic circuits.

Check to see that your training Kit Report sheet is completed and send it to NRI for grading.

While waiting for the return of this Report and for your next kit, prepare the parts you have left over for use in later kits. The parts left over are shown in Table I. *Remove the meter from its box and unsolder and remove the diodes and wires from the meter terminals.* Also, remove the solder lugs. Clean the meter terminals, and place the meter back in its box. Since the meter is a delicate instrument, be sure to put it in a safe place.

TABLE I

1	Pot mtg. bracket
1	Chassis plate
1	Etched circuit board with tube socket
1	Marking crayon
1	Meter
1	6-32 hex nut
2	4-40 hex nuts
1	1000-ohm potentiometer
1	470-ohm resistor
1	680-phm resistor
3	1000-ohm resistors
2	4700-ohm resistors
1	6800-ohm resistor
1	15,000-ohm resistor
1	22,000-ohm resistor
1	1/4" X 6-32 machine screw
2	1/4" X 4-40 machine screws
2	Large solder lugs
2	Silicon diodes
	Hookup wire
	Solder

IMPORTANT: Be sure to save ALL PARTS from this Kit, including screws and nuts, because you will need them later. Keep small parts in individual envelopes or boxes.

The following parts are attached to the chassis plate:

2 Flashlight cells
1 3-lug terminal strip
1 4-lug terminal strip
1 7-lug terminal strip
1 Small solder lug
5 1/4" X 6-32 machine screws
5 6-32 hex nuts
2 100,000-ohm resistors
1 82,000-ohm resistor

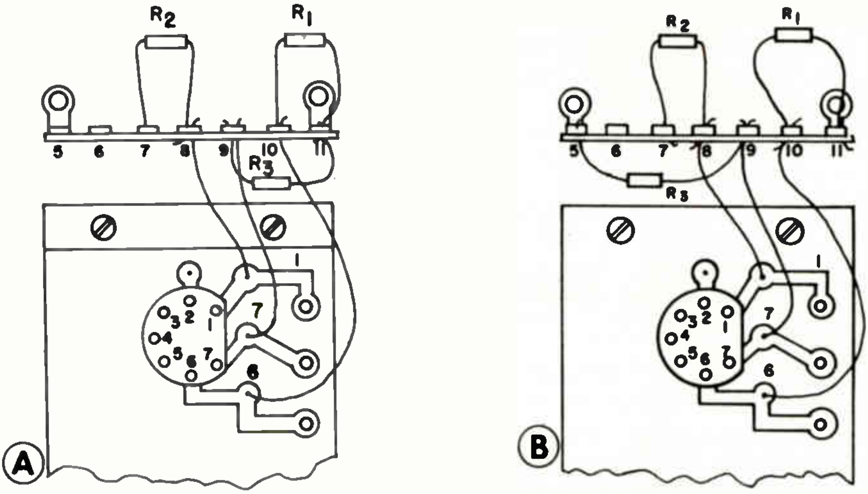

Fig. 4-6. Examples of how you could have wired the circuit used in Experiment 4.

Important Notice

As you use your soldering iron, a scale will accumulate on it. Eventually this scale will keep the iron from heating properly, and you will have to remove it. To do so, remove the tip from the barrel. Remove the scale from the tip and tap the end of the barrel against the workbench to loosen and remove the scale in the barrel. Refile the tip, if necessary, and put it back in the barrel.

If you have a soldering gun, poor contact may develop between the tip and the metal terminals of the gun. This can be eliminated by loosening and then tightening the nuts holding the tip in place. Make sure the nuts are tightened securely. Clean and re-tin the tip when it gets dirty, and replace it when it gets pitted.

Warning

You are expected to make a grade of A, B, C, or D for each group of ten experiments in this Practical Demonstration Course. If any of your reports come back to you marked "Low," you are to repeat the experiments and report statements marked "X" and then send in a complete new set of answers, using the new report blank we will send you. Since this procedure may mean that you will have to dismantle equipment that is to be used as a unit in succeeding experiments, do not begin work on the next Kit until you have received a grade of A, B, C, or D.

Each Day Counts . . .

Each day of our life offers its own reward for work well done, its own chance for happiness. These rewards may seem small, and these chances may seem petty in comparison with the big things we see ahead.

As a result, many of us pass by these daily rewards and daily opportunities, never recognizing that the final goal, the shining prize in the distance, is just a sum of all these little rewards we must win as we go along.

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ACHIEVEMENT THROUGH ELECTRONICS

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TRAINING KIT MANUAL

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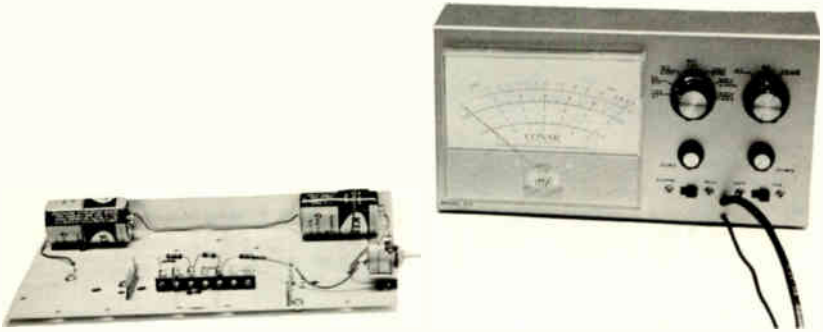
TRAINING KIT MANUAL 2T

PRACTICAL DEMONSTRATIONS IN BASIC ELECTRONICS



INDEX OF SECTIONS

JP2M772 1975 EDITION Litho in U.S.A.

INSTRUCTIONS FOR ASSEMBLING YOUR TVOM AND PERFORMING EXPERIMENTS 11-20

In the first part of this training kit you will build a modern, battery-operated, transistorized volt-ohmmeter (abbreviated tvom), which you will use in working the experiments in the second part of this training kit as well as in later training kits. This instrument is a professional quality meter and you should do the very best work that you can in assembling it. If you follow the instructions carefully and exactly, and use the soldering practices you learned in your first training kit, you should have no trouble at all in doing an excellent construction job.

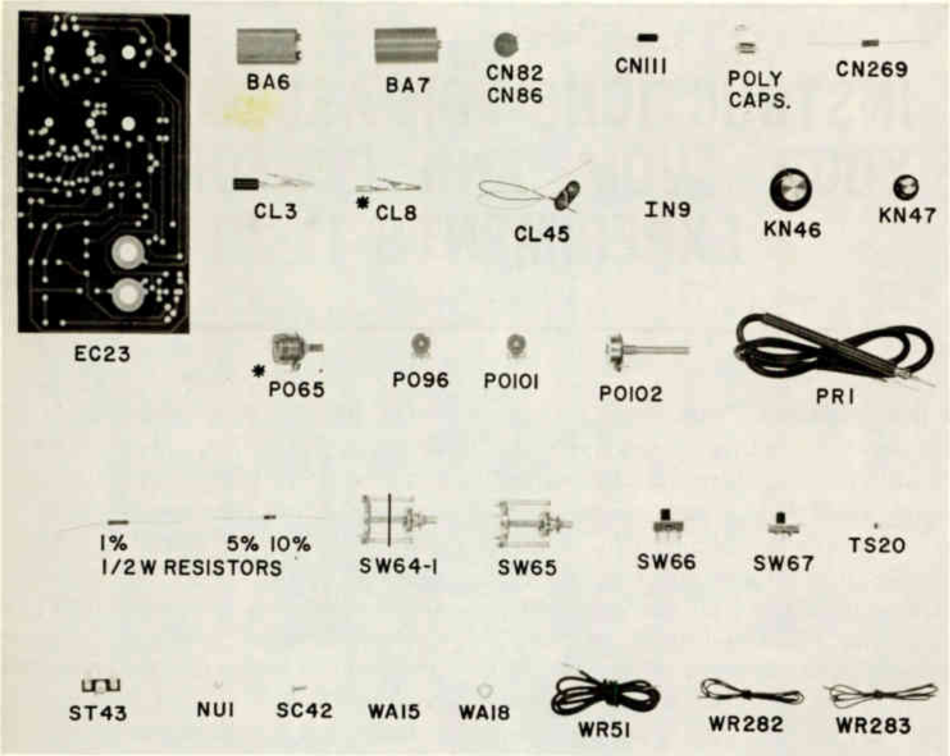
Most of the parts for the tvom are assembled on the large etched circuit board. Be very careful when soldering to the circuit board to follow the procedures given in the first training kit. If you have forgotten these procedures, or are in doubt in any way about how much heat or solder to use, go back and review the section in Training Kit 1T on soldering. The finished etched circuit board represents a fairly large amount of money, and any damage which you do to it may require replacing the entire circuit board, at your expense. We do not say this to frighten you, but merely to try to impress you with the importance of doing good work and of following the instructions *exactly*!

The parts supplied with this kit are shown in Fig. 1 and are listed below. Examine the parts you received to make certain they are all there and that no parts are obviously damaged. If any part is missing or damaged, be sure to let us know right away; we will supply the replacement part as quickly as possible so that you can begin construction of your tvom.

Before you start the actual assembly of your tvom, we want to bring to your attention certain facts about the resistors, capacitors and other parts supplied with this kit and others. This information will help you identify the various parts and ensure that you use the correct part for each step of the assembly.

CAPACITORS

There are four types of capacitors used in the assembly of your tvom: ceramic disc, polystyrene, tubular, and electrolytic. The disc capacitors are round and thin with lead wires coming from one edge. The ***value*** of the capacitor, ***type***, and ***working voltage*** are stamped on the body of the capacitor. The value will be either in picofarads (pf) or microfarads (mfd). If the number is a whole number,



* Experimental Parts

Fig. 1. Parts supplied with this kit are shown above and listed below.

Quan.	Part No.	Description	Price Each
1	BA6	9V battery	.68
1	BA7	1.5V "C" cell battery	.23
1	CL3	Alligator clip	.14
1	CL45	Battery clip	.26
1	CN82	.01 mfd, 2 KV disc cap	.22
3	CN86	.01 mfd, 1KV disc cap	.18
3	CN111	5-mfd elect. cap	.35
1	CN151	56 pf disc cap	.08
1	CN263	22 pf poly cap	.12
1	CN264	27 pf poly cap	.12
1	CN265	200 pf poly cap	.12
1	CN266	390 pf poly cap	.12
1	CN267	2000 pf poly cap	.15
1	CN268	3900 pf poly cap	.18
1	CN269	.012-mfd tubr. cap	.25
1	EC23A	Etched circuit board	4.17
1	IN9	2" spaghetti tubing	.15
2	KN46	Large knobs w/pointer	.40

Quan.	Part No.	Description	Price Each
2	KN47	Small knobs	.32
1	LU1	No. 6 solder lug	12/.15
5	NU1	6-32 hex nuts	12/.15
1	PA31	Panel	3.00
1	PO96	10K-ohm trimmer pot	.45
1	PO101	100K-ohm trimmer pot	.23
2	PO102	10K-ohm pot	.42
1	PR1	Probe	1.05
1	RE1	10-ohm, 5% res.	.24
1	RE3	100-ohm, 5% res.	.24
1	RE9	51K-ohm, 5% res.	.24
1	RE10	100K-ohm, 5% res.	.24
1	RE25	10-megohm, 5% res.	.24
1	RE33	22K-ohm res.	.15
1	RE34	27K-ohm res.	.15
1	RE39	1-megohm res.	.15
1	RE44	2.2-megohm, 10% res.	.15
2	RE50	6.8K-ohm res.	.15

Quan.	Part No.	Description	Price Each
1	RE73	1-megohm, 5% res.	.24
1	RE74	10K-ohm, 5% res.	.24
1	RE94	10K-ohm, 1% res.	.78
1	RE95	30K-ohm, 1% res.	.78
1	RE96	60K-ohm, 1% res.	.78
1	RE97	300K-ohm, 1% res.	.78
1	RE98	600K-ohm, 1% res.	.78
1	RE99	3-megohm, 1% res.	.78
1	RE162	6-megohm, 1% res.	.78
1	RE163	2.2-megohm, 1% res.	.78
1	RE164	1K-ohm, 5% res.	.24
5	SC42	6-32 X 3/8" Phillips head screws	12/.25

Quan.	Part No.	Description	Price Each
1	ST43	2-lug terminal strip	.06
1	SW64-1	Function switch with nut and flat washer	1.75
1	SW65	Range switch	1.76
1	SW66	DPDT slide switch	.16
1	SW67	SPST slide switch	.21
2	TS20	N channel FETs	1.00
5	WA15	No. 6 lockwashers	12/.15
4	WA18	No. 10 flat washers	12/.15
1	WR51	Ground wire	.30
1	WR282	Stranded black wire, 2'	.15
1	WR283	Stranded red wire, 2'	.15

All resistors are 1/2-watt, 10% tolerance unless otherwise specified.

2T EXPERIMENTAL PARTS

Quan.	Part No.	Description	Price Each
1	CL8	Alligator clip	.07
1	PO65	500K-ohm pot w/switch	.95
1	RE31	10K-ohm res.	.15
1	RE32	18K-ohm res.	.15
1	RE33	22K-ohm res.	.15
1	RE36	100K-ohm res.	.15
1	RE37	220K-ohm res.	.15
1	RE38	470K-ohm res.	.15
1	RE39	1-megohm res.	.15
2	RE42	10-megohm res.	.15
1	RE45	3.3K-ohm res.	.15

All resistors are 1/2-watt, 10% tolerance unless otherwise specified.

such as 120, the value is in pf. If the number has a decimal, such as .01 or .1, the value is in microfarads. The type may be any of several numbers or letters and for our purposes will be unimportant. Likewise, the voltage rating is also relatively unimportant in this kit. You should be certain, however, that the voltage rating is at least as great as that indicated for the part in the parts list.

The polystyrene capacitors are tubular in shape and have a thin lead wire coming from each end. These capacitors have a clear plastic outer covering through which you can see the aluminum foil of the capacitor plates. As with the disc capacitors, the value of the capacitor is stamped on the outside of the capacitor in pf or mfd. The largest polystyrene capacitor, CN268, may be stamped "3900" or ".0039"; either indicates a value of .0039 mfd.

There is only one tubular capacitor, CN269, a .012-mfd capacitor. This capacitor will have its value stamped on the outside of the case.

Electrolytic capacitors have polarity. They must be put into the circuit exactly as indicated, otherwise they may be damaged. The positive lead of the electrolytic, CN111, can be identified by a "+" mark printed at one end, or by the fact that one end will be colored red. The value and voltage rating are printed on the side of the capacitor.

RESISTORS

Many of the resistors used in this kit are similar to the ones you used in the first training kit. They are 1/2-watt resistors and are identified by their color code. Although you do not need to memorize this color code, it will be to your advantage to do so, as it will speed up your work to be able to identify resistors at a glance.

The fixed, color-coded resistors supplied in this kit are of 10% and 5% tolerance. It is very important that you use the correct resistor in the correct circuit. While we might possibly substitute a 5% (gold) tolerance resistor for a 10% (silver) tolerance resistor, you should *not* use a 10% tolerance resistor where a 5% tolerance resistor is called for.

There are other fixed resistors in this kit that may or may not be color-coded. These are the 1% precision resistors used in the input divider chain of the tvom. It is very important that these resistors be used *only* where called for in the instructions. If these resistors are *not* color coded, then the value will be printed right on the body of the resistor. On these resistors, the letter "K" stands for 1000, and "M" stands for one million; thus, "10K" means a 10,000-ohm resistor, and "2.2M" means a 2,200,000-ohm or 2.2-megohm resistor. If these resistors are color coded the fourth or tolerance band will be brown.

OTHER PARTS

The other parts you receive in this kit should be fairly easy to identify. For example, the two rotary switches, SW64-1 and SW65, are similar in appearance but the SW64-1 switch has two switch wafers while the SW65 switch has only one switch wafer. You can also note that the SW64-1 has 11 clips coming from the rear of the switch, while the SW65 has only 8 clips.

The two slide switches, SW67 and

SW66, do not have the part number stamped on them. They may be identified by counting the number of lugs they have; SW67 has two and SW66 has six.

The potentiometers all have their part number and value stamped on them. Be particularly careful not to confuse the two small trimmer potentiometers, PO96 and PO101. They both look alike; however, the PO96 has a value of 10K ohms and the PO101 has a value of 100K ohms.

You should have no difficulty identifying the remaining parts in this kit, using Fig. 1 and the various descriptions of the parts in the parts list under Fig. 1.

Figs. 2, 3 and 4 and a schematic diagram of the complete tvom are on the two pages in the center of this manual. You can loosen the staples and remove these pages when you assemble the tvom. When you have finished assembling the tvom, replace the pages in the center of the manual so you will have the schematic handy if you should ever need it.

Assembling Your TVOM

The assembly of your tvom is divided into several stages. In each stage you will perform only a few simple steps. In this way you can stop at frequent intervals and check to make certain that you have done what was expected for each stage. Or, if you are interrupted for any reason, there are very convenient stopping points. Just note where you stopped so that you can pick up your work conveniently.

Before you begin the assembly of any stage, read over the entire list of instructions and make sure you know exactly which parts you will need. Then select the required parts and perform the assembly steps indicated.

When you install parts on the etched circuit board, the assembly steps are given as numbered blocks around a picture of the board with arrows going from the block to the location on the board where the part is to be placed. Use the skills you learned in the first kit to install, solder and cut off leads for each step.

Some parts are installed from the foil side of the board. Be careful not to let solder bridge from one place to another when you work on the foil side of the board, and remember to clip off leftover lead lengths on the phenolic side of the board.

After you have assembled the etched circuit board you will install the meter and other parts on the panel. Then you will wire the battery, probe and switches. Finally you will fasten the circuit board to the panel and meter and perform the calibration procedure.

ETCHED CIRCUIT BOARD ASSEMBLY
STAGE I

Before you begin the first assembly stage, check to make certain that your soldering iron is clean and well tinned. If it is not in good condition, plug it in and clean and retin it as described in the first training kit.

Clear a space on your worktable and put a clean, soft cloth down on which to place the circuit board as you work on it. This will protect both the circuit board and the table. Identify and gather the following parts:

1 Etched circuit board (EC23A)
1 Battery clip connector (CL45)
1 56 pf disc capacitor (CN151)
1 .01 mfd, 1KV disc capacitor (CN86)
2 10K-ohm pots (PO102)
1 10K-ohm trimmer pot (PO96)
1 100K-ohm trimmer pot (PO101)
2 6.8K-ohm, 10%, 1/2-watt resistors (RE50, blue-gray-red-silver)
1 22K-ohm, 10%, 1/2-watt resistor (RE33, red-red-orange-silver)
1 27K-ohm, 10%, 1/2-watt resistor (RE34, red-violet-orange-silver)
1 51K-ohm, 5%, 1/2-watt resistor (RE9, green-brown-orange-gold)
1 1-megohm, 10%, 1/2-watt resistor (RE39, brown-black-green-silver)
2 N channel FETs (TS20)
Red stranded wire
Black stranded wire
Hookup wire (from Kit 1T)
Solder

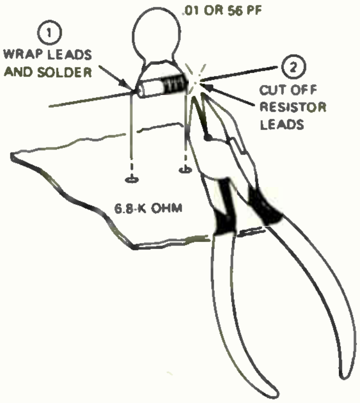


Fig. 2. Detail A.

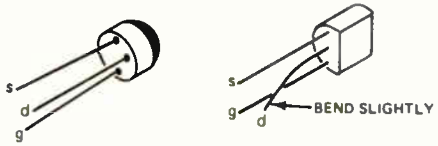


Fig. 2. Detail B.

The assembly instructions are given in Fig. 2 (centerfold).

Prepare a 7-1/2" length of red stranded wire and a 7-1/2" length of black stranded wire for use in Steps 5 and 6. Remove 1/4" of the insulation from each end of both wires, and twist the strands at the end of each wire tightly together. Tin all four ends with solder to hold the strands together. When you install these wires in Steps 5 and 6, the other end of each wire will remain free.

The red lead of the 9V battery connector installed in Step 11 goes to the "+9V" location while the white lead goes to the "-9V" location.

In Step 8 of Fig. 2 you will install a parallel combination of a 6.8K-ohm resistor and a .01 mfd disc capacitor. Detail A of Fig. 2 shows how to make this combination. Wrap each capacitor lead one time around each resistor lead close to the body of the resistor. Solder both of these connections, then clip off the resistor leads as shown. Insert the capacitor leads into the 6.8K-ohm location on the circuit board and solder as you would any other component. The 56 pf disc capacitor and the second 6.8K-ohm resistor used in Step 12 are installed in the same manner.

The two potentiometers installed in Steps 1 and 2 may have a large nut on the bushing. Remove and set aside these nuts, if present, as they will not be needed to hold the potentiometers in place. The potentiometers are installed by passing the shaft through the hole from the phenolic side of the board. Rotate the body of the control so that the three solder pins of the potentiometer line up with the corresponding holes in the circuit board as shown. With the holes lined up, push the control fully forward so the pins go through the board and the front of the control is tight up against the board. Turn the board over, making sure that the control stays tight up to the board, and solder the three pins to the foil. Do *not* try to cut off the ends of the pins.

Detail B for Fig. 2 shows two possible types of TS20 you may have received with this kit. The bottom side (lead side) of the transistors is shown. The transistor on the left in Detail B has a round case and the three leads come from the bottom of the case in a triangular configuration. The gate (g), source (s), and drain (d) leads are identified in Detail B. These symbols (g, s, d) correspond to the holes marked g, s, d on the circuit board at locations Q_1 and Q_2 (Steps 9 and 10) of Fig. 2.

The transistor on the right in Detail B has a black plastic body which is "D" shape in cross section. The three leads, g, s, d, are "in-line" on this transistor and the middle lead will have to be bent outward slightly in order to have the leads fit the holes in the circuit board.

When you are sure you have identified the leads correctly and are ready for Steps 9 and 10, push the three leads into the corresponding holes of the circuit board so that they protrude about 1/8" from the foil side of the board. Turn the board over, and while holding the transistor in place, quickly solder each of the three leads to the foil.

As mentioned earlier, be certain you use the correct trimmer potentiometers in Steps 13 and 15.

When you are certain you understand all of the steps, proceed to install the parts for Stage I, shown in Fig. 2. As you complete each step, place a check mark in the space ( ) provided.

ETCHED CIRCUIT BOARD ASSEMBLY STAGE II

In this stage of the assembly you will install the 1% resistors and the capacitors on the circuit board. Gather the following parts:

1 2.2 meg, 1/2W, 1% resistor (RE163)
1 6 meg, 1/2W, 1% resistor (RE162)
1 3 meg, 1/2W, 1% resistor (RE99)
1 600K, 1/2W, 1% resistor (RE98)
1 300K, 1/2W, 1% resistor (RE97)
1 60K, 1/2W, 1% resistor (RE96)
1 30K, 1/2W, 1% resistor (RE95)
1 10K, 1/2W, 1% resistor (RE94)
1 .01-mfd, 2KV disc capacitor (CN82)
1 22-pf polystyrene capacitor (CN263)
1 27-pf polystyrene capacitor (CN264)
1 200-pf polystyrene capacitor (CN265)
1 390-pf polystyrene capacitor (CN266)
1 2000-pf polystyrene capacitor (CN267)
1 3900-pf polystyrene capacitor (CN268)
1 .012-mfd tubular capacitor (CN269)
3 5-mfd electrolytic capacitors (CN111)

There are no special precautions to observe in this stage of the assembly, other than the polarity of the three electrolytic capacitors installed in Steps 5, 6, and 11. The one used in Step 5 has its "+" end to the *left*, the one used in Step 6 has its "+" to the *right*, and the one used in Step 11 has its "+" end *down*.

You will notice that the hole spacing for some of the capacitors is much greater than the length of the capacitors. Simply center the body of the capacitor between the holes and bend the leads to fit.

Now proceed to install the parts in accordance with Fig. 3, which is in the centerfold of this manual.

ETCHED CIRCUIT BOARD ASSEMBLY STAGE III

In this stage of the assembly of your circuit board you will install components on the foil side of the board as shown in Fig. 4 (centerfold). You will need:

1 Range switch (SW65)
1 Function switch (SW64-1)
1 .01 mfd, 1KV disc capacitor (CN86)
1 10-ohm, 1/2-watt, 5% resistor (RE1, brown-black-black-gold)
1 100-ohm, 1/2-watt, 5% resistor (RE3, brown-black-brown-gold)
1 1K-ohm, 1/2-watt, 5% resistor (RE164, brown-black-red-gold)
1 10K-ohm, 1/2-watt, 5% resistor (RE74, brown-black-orange-gold)
1 100K-ohm, 1/2-watt, 5% resistor (RE10, brown-black-yellow-gold)

1 1 megohm, 1/2-watt, 5% resistor (RE73, brown-black-green-gold)
1 10 megohm, 1/2-watt, 5% resistor (RE25, brown-black-blue-gold)
Hookup wire from last training kit

The two rotary switches, SW64-1 and SW65, can only fit into the holes in the circuit board one way – the right way. Examine SW65 carefully. Notice that it has eight solder lugs pointing back (away from the rear of the switch wafer) and eight solder terminals on the front side of the switch wafer. When the switch is correctly positioned, the eight lugs on the rear of the wafer will fit into the corresponding holes of the circuit board; the flat locating lug on the front of the switch will be to your left (see Fig. 4); and the two nuts which hold the switch together will fall into two larger holes of the circuit board.

If any of the lugs on the rear of the switch wafer are out of line, they must be straightened or it will be impossible to install the switch correctly. With the lugs correctly lined up, you should be able to push the switch firmly up against the board so that the shoulder of every lug is in firm contact with the foil and protrudes the same distance from the phenolic side of the board. The switch shaft will then be perpendicular to the surface of the circuit board.

Be very certain that each switch is properly installed before you solder it to the foil. If even one lug misses its hole, or if the switch is at a slight angle, your meter will not operate properly and you probably will not be able to install the board into the cabinet.

When you are absolutely certain that you have the range switch, SW65, properly positioned, solder each of the eight lugs to the foil. To do this, make sure your soldering iron is clean and hot. Melt a small amount of solder on the tip of the iron to "wet" it (this promotes good heat transfer) and touch the tip to the solder lug and the foil at the same time, just as you did when you soldered the tube socket to the circuit board in the first kit. Add enough solder so that it flows smoothly around the solder lug and also adheres to the foil. Remove the iron and allow the joint to cool. When you are satisfied that you have a good connection, proceed to solder the remaining lugs to the foil.

SW64-1 is installed in exactly the same manner. This switch has eleven lugs to be soldered to the foil and only one solder terminal on the front of the rear switch wafer. (This terminal is *not* shown in Fig. 4 as it is not used.) There are also two terminals on the front switch wafer. Position the SW64-1 as indicated in Fig. 4 and solder all eleven lugs to the foil as you did for the range switch.

In Step 1, install the .01 mfd capacitor by cutting both leads to 1/2" and soldering them to the circuit board foil, as shown in Fig. 4 and Detail A. First tin the circuit board foil in the areas shown and press the capacitor leads as close as possible against the circuit as you melt the solder on the board. Avoid shorting the leads to any of the adjacent foils; the blue solder mask material is a good insulator but is easily cut, so be careful.

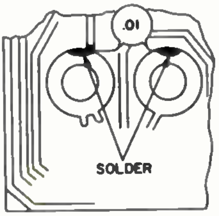


Fig. 4, Detail A.

The only remaining parts to install are the seven 5% resistors and three lengths of hookup wire. The first piece of hookup wire goes from hole number 8 of the circuit board to solder terminal 8 of SW65 as indicated in Step 9 of Fig. 4.

In Step 10, connect a 5-1/4" length of hookup wire from lug 2 of the front wafer of the Function switch to the hole marked "J" on the foil. Solder both connections. Similarly, in Step 11 connect a 7-1/2" length of hookup wire from lug 1 of the Function switch to hole "H". Solder both connections, then dress both leads close to the board, as shown in Fig. 4.

The 5% resistors go from the numbered holes to the solder terminals of SW65. Position each resistor as shown and bend one lead at right angles so it will go through the numbered hole in the board. The body of the resistor should be parallel to the circuit board and at a distance from the circuit board as determined by the location of the solder lug on SW65. As each resistor is soldered in place, cut off the excess lead length from both ends.

When you are sure you understand how to install the resistors and the hookup wire, proceed to do the steps indicated in Fig. 4.

This completes the preliminary assembly of the tvom. You will notice that there are several places on the circuit board where parts are indicated, but you have not installed the parts. These parts are installed in the next training kit to enable you to measure ac voltages. The instrument you construct in this training kit will enable you to measure dc volts in seven ranges, 1.2 volts to 1200 volts, and to measure ohms in seven ranges, R X 1 to R X 1 megohm.

MOUNTING PARTS ON THE PANEL

At this point in the assembly of your tvom you have almost completed your wiring. All that remains to be done is to mount the meter, two slide switches, assemble the probe and ground lead, install the batteries and connect the etched circuit board to the panel wiring.

You will now install the meter, prewire and mount the two switches, and assemble and install the probe and ground leads. You will need the following parts:

1	Panel (PA31)
1	Meter (ME21) and hardware (from Kit 1T)
1	.01 mfd, 1KV disc capacitor (CN86)
1	2.2 megohm, 10% resistor (RE44)
1	Probe (PR1)
1	Ground wire (WR51)
1	Alligator clip (CL3)
1	SPST slide switch (SW67)
1	DPDT slide switch (SW66)
5	6-32 X 3/8" Phillips head screws (SC42)
5	No. 6 lockwashers (WA15)
5	6-32 hex nuts (NU1)
1	2-lug terminal strip (ST43)
2	Large knobs with pointer (KN46)
2	Small round knobs (KN47)
1	2" length of insulating tubing (spaghetti, IN9)
1	No. 6 soldering lug (LU1)
	Red stranded wire
	Black stranded wire
	Hookup wire (from Kit 1T)
	Solder

Locate the panel and put it on your work area, face up in the position shown in Fig. 5. You will use the panel as a temporary support to hold the two slide

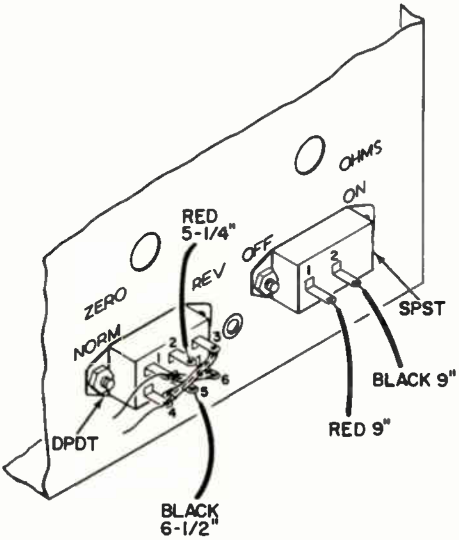


Fig. 5. Prewiring the slide switches.

switches as you wire them. As you work on the front of the panel, be very careful not to scratch or mar it with your screwdriver. Be very careful not to drip any solder onto the panel or touch the panel with your soldering iron.

Temporarily fasten the SPST slide switch as shown in Fig. 5. Position the switch so the two lugs are to the left. One screw and nut are all you need to hold the switch temporarily in place.

Prepare a 9″ length of red stranded wire by removing 3/8″ of the insulation from one end of the wire. Twist the strands tightly together and tin them with your soldering iron and solder to hold the wires together . . . . (✓)

Do the same thing for the other end of the red wire . . . . (✓)

Bend a hook in one end of the wire and pass it through terminal 1 of the SPST switch. Bend the hook closed and solder terminal 1 . . . . (✓)

In a similar manner prepare both ends of a 9″ black stranded wire. Solder one end of the wire to terminal 2 of the SPST switch . . . . (✓)

Remove the SPST switch and set it aside . . . . (✓)

Mount the 6-terminal DPDT slide switch as shown. Use one 6-32 screw and nut. NOTE: The switch can be mounted in either of two positions, both are correct . . . . (✓)

Prepare a 6-1/2″ length of black stranded wire as you did above and solder one end to terminal 5 . . . . (✓)

In a similar manner prepare a 5-1/4″ length of red stranded wire and solder one end to terminal 2 . . . . (✓)

Strip 2-1/4″ of insulation from a piece of solid hookup wire (left over from the last kit). Cut off the bare wire and permanently solder one end to terminal 3 of the DPDT switch . . . . (✓)

Cut off a 1/2″ length of the insulating tubing (spaghetti) and slip it over the bare wire soldered to terminal 3 . . . . (✓)

Feed the free end of the bare wire coming from terminal 3 through terminal 4, leaving all the extra wire on the other side of terminal 4. The spaghetti should be between terminal 3 and terminal 4. Solder terminal 4 . . . . (✓)

In a similar manner prepare a 2-1/4″ length of bare wire and a 1/2″ length of

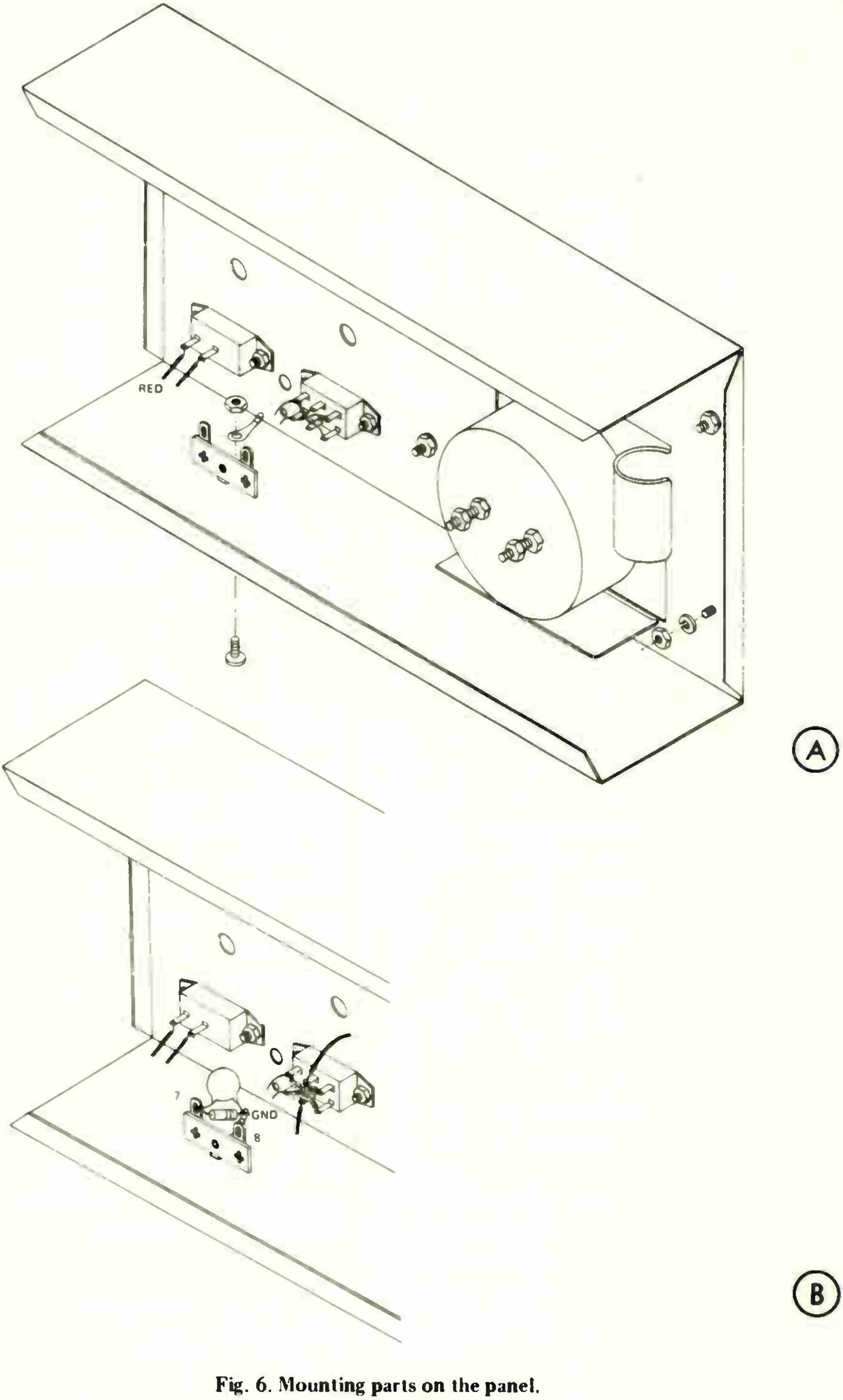


Fig. 6. Mounting parts on the panel.

spaghetti, and connect terminals 1 and 6, leaving the extra wire to the left of terminal 1 as shown in Fig. 5 . . . . . .(✓)

After you have the wires in place on the DPDT switch, remove the switch and set it aside . . . .(✓)

Refer to Fig. 6 for the following steps.

Position the ME21 meter over the large cutout in the panel. The four mounting screws should line up with four of the holes in the panel, as shown, with the barrel of the meter passing through the large cutout in the panel. With the meter firmly up against the panel, install a lockwasher and nut (meter hardware) on each of the four mounting screws. Save the four large nuts (meter hardware) as they will be used later . . . .(✓)

CAUTION: With the meter now installed on the panel, be especially careful not to scratch or otherwise damage the meter face. Always place a clean, soft cloth on your work area to protect the meter as you work behind the panel.

Position the SPST slide switch as shown in Fig. 6 with the red wire to your left. Line up the two mounting holes with those in the panel and secure the switch with two 6-32 X 3/8" Phillips head screws, two No. 6 lockwashers and two 6-32 hex nuts . . . .(✓)

Position the DPDT switch as shown in Fig. 6 with the bare wires from terminals 1 and 4 to your left. Line up the two mounting holes with those in the panel and secure the switch with two 6-32 X 3/8" Phillips head screws, two No. 6 lockwashers and two 6-32 hex nuts (✓)

Before you mount the terminal strip, use a knife or screwdriver to scrape away the paint from around the mounting hole. Scrape off the paint on the *inside* only (✓)

Install the 2-lug terminal strip and solder lug as shown in Fig. 6A with the 6-32 X 3/8" Phillips head screw, a No. 6 lockwasher and a 6-32 hex nut. Place the No. 6 solder lug between the terminal strip and the lockwasher . . . .(✓)

Referring to Fig. 6B, connect the 2.2 megohm resistor from terminal 7 to the ground lug. Keep the resistor leads short and do not solder either connection (✓)

Connect the .01 mfd disc capacitor from terminal 7 to the ground lug. Keep the leads short and solder *only* the ground lug . . . . (✓)

Examine the red test probe with the coaxial cable attached (PR1). You will notice that the end of the probe lead looks like Fig. 7 with a bare wire surrounded by a length of insulation, a braided shield wire and an outer covering. To install the probe lead, pass the end of the lead through the bushing in hole T from the front of the panel . . . . . (✓)

Rotate the lead wire so that the bare wire can be connected to terminal 8 of the 2-lug terminal strip and the braid lead

Fig. 7. End of probe lead.

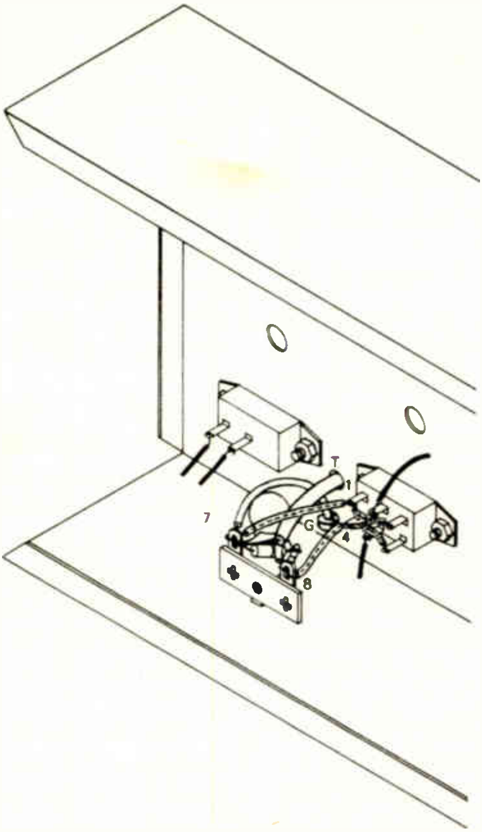


Fig. 8. Connections to terminals 7 and 8 of the 2-lug terminal strip.

can be connected to terminal 7 as shown in Fig. 8. Make these connections but do not solder . . . . (✓)

Remove 1/2" of the rubber insulation from each end of the 3′ ground wire (WR51), twist the strands and tin the wire . . . . (✓)

Pass one end of this wire through the small bushing at hole G, and tie a knot in the wire approximately 2" from the end. Bring the end of the wire over to terminal 7 and connect but do not solder . . . . (✓)

Cover the bare wire coming from terminal 1 of the switch with a length of spaghetti. Connect and solder this wire to terminal 7 of the 2-lug strip. Be sure to solder all the leads at this terminal. You will probably have to heat this connection for quite a long time before the solder will flow smoothly over all five leads . . . . (✓)

In a similar manner, cover the bare wire coming from terminal 4 of the switch with a length of spaghetti and solder the wire to terminal 8 of the 2-lug strip . . . . (✓)

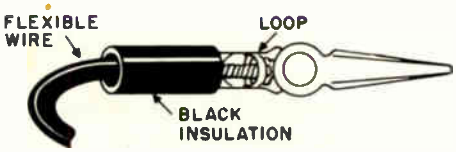


Fig. 9. How to attach the flexible wire to the alligator clip.

Now take the alligator clip with the plastic handle (CL3) and pass the free end of the 3′ ground wire through the plastic handle and the solder loop as shown in Fig. 9. Solder the ground wire to the solder loop . . . . (✓)

This completes the panel assembly. You will next fasten the etched circuit board into position, complete the wiring and then calibrate your tvom.

COMPLETING AND CALIBRATING THE TVOM

You will need the following parts:

1	1.5-volt "C" size flashlight cell (BA7)
1	9-volt battery (BA6)
2	Control nuts
2	Large flat washers
4	No. 10 washers (WA18)
4	10-32 nuts (meter hardware)
	Solder

With the panel and etched circuit board in the positions shown in Fig. 10, take the red and black wires which are fastened to terminals 1 and 2 of the SPST switch, and twist them together loosely. Insert the black lead into the upper hole of the etched circuit board labeled "SW"

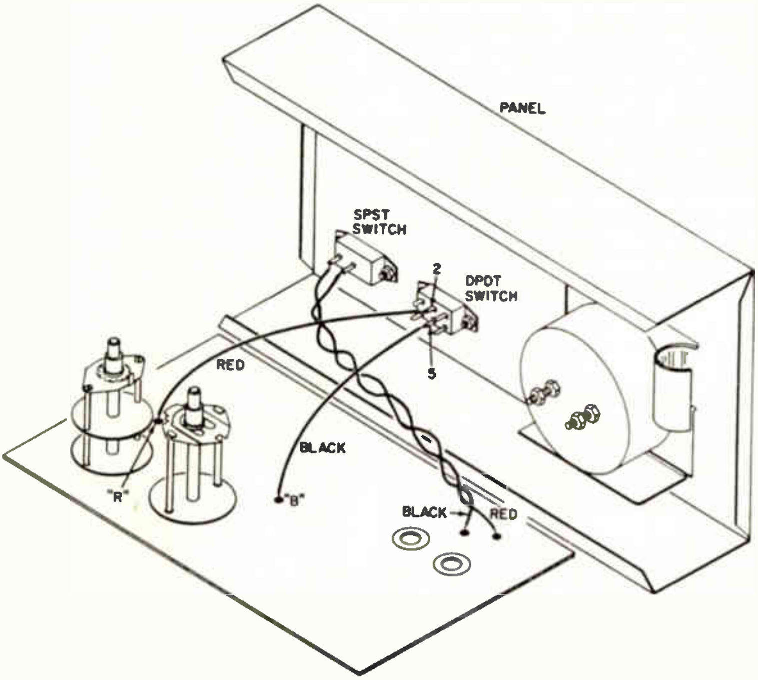


Fig. 10. Connecting the wires from the panel to the circuit board.

and the red lead into the lower hole labeled "SW" as shown. Solder both leads and clip off any excess lead length . . (✓)

Place the free end of the red lead from terminal 2 of the DPDT switch into the hole labeled "R" near the function switch. Solder this lead and clip off any excess lead length from the phenolic side of the board . . . . (✓)

In a similar manner, solder the black wire from terminal 5 of the DPDT switch to the hole labeled "B" on the foil side of the board . . . . (✓)

Take two of the 10-32 nuts supplied with the meter and run one down on each meter terminal stud so the top of the nut is 5/16" from the end of the stud as shown in Fig. 11 . . . . (✓)

Place one No. 10 flat washer on each meter stud . . . . (✓)

Now carefully rotate the etched circuit board into position so that the two switch shafts will come through the upper holes in the panel and the two potentiometer shafts will come through the lower holes in the panel. The two meter studs should pass through the two large holes of the etched circuit board. Make certain that the wires from the two slide switches on the panel are free and not pinched between the switch bushings and the panel. The locating lugs of the two switches should pass through the small slots in the panels.

When you are sure the switches are correctly seated, place a large flat washer over each of the switch bushings and lightly fasten the switches with the two large control nuts. Tighten these nuts only "finger tight" for now . . . . . . (✓)

Now sight along the etched circuit board from the end near the meter. The board should be straight and resting on the two washers on the meter studs. If the board is "bowed" out or must be pushed in to rest on the washers, adjust the position of the 10-32 nuts on the meter studs so the board rests on the washers without bowing . . . . (✓)

Place the remaining No. 10 flat washers over the meter studs and fasten lightly (finger tight) with the remaining 10-32 nuts. Be careful not to strike Q_1 or Q_2 as you tighten the nuts . . . . (✓)

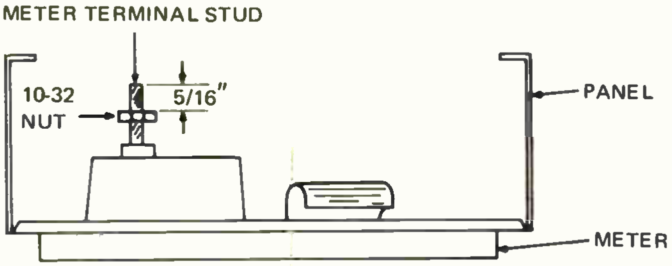


Fig. 11. Put 10-32 nuts on meter terminal studs 5/16" from end.

Now look at the two potentiometer shafts coming from the front of the panel. They should be fairly well centered in the panel holes. If they are not, slightly loosen the two control nuts, which secure the two rotary switches and the two meter stud nuts. With these four nuts loosened, you can move the etched circuit board around enough to center the potentiometer shafts. With the shafts centered, hold the circuit board in place and tighten securely the two control nuts of the rotary switches . . . .(✓)

Now tighten securely the two nuts that fasten the circuit board to the meter studs, being careful not to damage Q_1 or Q_2 . . . .(✓)

Now take the 1.5-volt "C" flashlight cell and tin a spot in the center of the bottom of the cell. Also tin the positive terminal of the cell . . . .(✓)

Slip the "C" cell into the curved clamp beside the meter barrel, so that the positive terminal is toward the top of the panel . . . .(✓)

Now locate the red and black wires which go to the + and − 1.5V locations on the circuit board. Bring the black wire over to the battery and solder to the negative battery terminal . . . .(✓)

In a similar manner solder the red wire to the positive battery terminal . . . .(✓)

Make sure that the SPST slide switch is in the "off" position, then take the battery clip (connected to the "9V" location on the circuit board) and snap the connector onto the terminals of the 9-volt battery . . . .(✓)

If you look into the end of your tvom where the "C" cell is mounted, you will see that there is a small shelf of metal directly below the barrel of the meter. This shelf forms a spring clamp which will hold the 9-volt battery securely. To install the 9-volt battery, bend the shelf up very slightly with your finger and slide the 9-volt battery under the shelf so that it rests on one side of the battery, holding it between the shelf and the inside wall of the panel . . . .(✓)

Take one of the large knobs, with pointer, and check to see that the set screw does not protrude into the shaft opening. Place this knob on the shaft of the range switch so that the set screw will bear on the flat part of the shaft. Tighten the set screw . . . .( )

In a similar manner install the other pointer knob on the function switch (✓)

There are no flats on the ZERO adjust and OHMS adjust potentiometer shafts so install the two small round knobs on these shafts in any position you like .(✓)

This completes the assembly of the DC and OHMS portion of your tvom. Before you can use it, you must balance the circuit and calibrate it. These procedures are covered in the next section.

Balancing and Calibrating the TVOM

To balance and calibrate the tvom, clip the ground lead to the probe tip and set the controls as indicated:

FRONT PANEL	
Range Switch	3V - X10
Function Switch	DC
Polarity Switch	NORM
ON-OFF Switch	OFF
Zero Control	Fully Clockwise
Ohms Control	Fully Counter-clockwise

CIRCUIT BOARD	
Balance Pot	Mid-position
DC Cal Pot	Mid-position

Fig. 12 shows the settings of the front panel controls. The two potentiometers on the circuit board can be adjusted either by using your fingers on the edge of the adjusting disc or by using a screwdriver with a small blade through the access holes in the edge of the panel. These holes are identified by "DC" and "BAL" stamped in the metal over the holes. For ease of adjustment, it is suggested that you use the small-blade screwdriver to make these adjustments. You can practice finding the potentiometer slot with your screwdriver before you start the actual adjustments.

MECHANICAL ZERO ADJUST

Place the tvom on your work area so that the meter and controls are facing up. Look carefully at the pointer of the meter. It should be resting squarely over the "zero" marks at the left side of the scales. If the pointer is not over the zero marks, turn the plastic screw in the lower center of the meter with a screwdriver, until the pointer is over the zero marks as shown in Fig. 13. Use a screwdriver which fits the plastic screw slot or you may damage the screw. You will seldom have to make this adjustment, as the mechanical zero will not usually change. However, if you do need to do it at some later time,

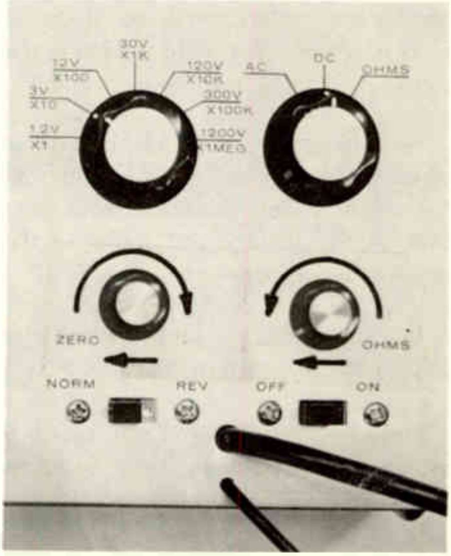


Fig. 12. Setting of the front panel controls.

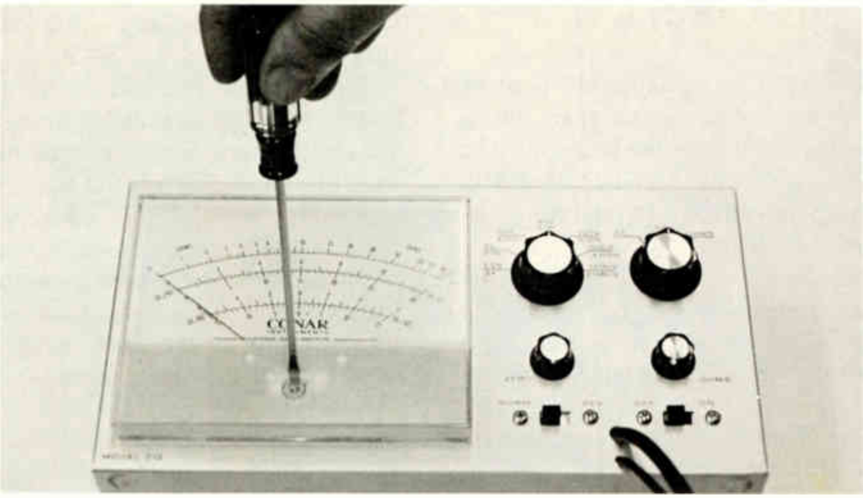


Fig. 13. Adjusting the meter pointer to zero.

remember that the tvom must be OFF when you make the adjustment.

BALANCING THE TVOM

The two field-effect transistors used in your tvom in all likelihood have slightly different characteristics even though they are both the same type of transistor. Since the basic principle of the tvom is one of a balanced bridge circuit, we must adjust the operating voltages of the two transistors so that the bridge circuit is truly balanced. There are two controls which affect the balance of the circuit. The first control is the zero adjust control on the front panel. This control is used on a day-to-day basis to insure correct balance. It could be considered a "fine tuning" adjustment. The other control is the balance potentiometer on the circuit board. This control is used to compensate for the difference in transistor characteristics, as mentioned earlier.

With all the controls adjusted and set as previously indicated, you are now ready to balance the circuit. Read the following instructions through first and then, when you are sure you know what to do, carry them out to balance the circuit.

With the tvom facing up in front of you, insert your screwdriver through the hole marked BAL and into the slot of the balance potentiometer. When you turn the power on with the panel switch, the meter pointer will, in all probability, go upscale past the highest marking on the right or, it may possibly move violently to the left, past zero. In either case, quickly adjust the balance potentiometer with your screwdriver to bring the pointer approximately to midscale (15). Now turn the zero adjust knob to the left (counterclockwise) to see if you can bring the pointer back to zero with the zero adjust. Readjust the balance potentiometer slightly, if necessary, so that you can zero the meter with the zero adjust control. This provides the preliminary balance of the tvom, and after you carry out the calibration procedure you may have to readjust the balance control.

CALIBRATING THE TVOM

With the tvom on and in the position used in the balancing procedure, unclip the ground lead from the probe tip. The range switch should be set to 3V - X10, the function switch to DC and the polarity switch to NORM.

Touch the tip of the probe to the positive terminal of the "C" cell and the meter pointer should swing upscale, to the right. Now, while holding the probe on the positive terminal of the "C" cell, insert your small-blade screwdriver through the hole labeled "DC" and engage the slot of the DC CAL potentiometer. Slowly adjust this control until the pointer indicates exactly 1.55 volts on the 3-volt scale. The pointer will then be just 1/2 division to the right of the center mark on the 3-volt scale. This is halfway between the 1.5-volt marking and the next (1.6-volt) marking and can be precisely located by using the short mark on the other (12-volt) scale as you learned in the last training kit . . . . (✓)

When you have made this adjustment, remove the probe from the "C" cell and touch it to the ground clip. Readjust the zero adjust control for zero and repeat the procedure . . . . (✓)

Now turn the zero adjust knob fully clockwise and note the scale reading. If it is not indicating at least 2 volts on the 3-volt scale, readjust the balance control with your screwdriver to bring it to about 2 volts. If you had to adjust the balance control, you will have to check the calibration procedure you just went through, following each step exactly. When you have completed the calibration and balancing, record the scale reading you obtain with the zero adjust control fully clockwise here: 2.75

This reading will serve as a check of the battery condition later on. As the battery voltage decreases, the reading you obtain with the zero adjust control fully clockwise will change. It may go higher or lower, depending upon the characteristics of the particular transistors in your tvom. In any case, if this reading changes more than 0.5 volt on the 3-volt range, you should replace the 9-volt battery.

If you should ever have occasion to replace one or both of the transistors, you will have to go through the entire balance/calibration procedure again. However, if you use your tvom intelligently and observe the operating procedures which follow in your second experimental manual, you should not need to replace a transistor.

IN CASE OF DIFFICULTY

If you are not able to calibrate your tvom according to the preceding instructions, one or more of the parts may be defective, there may be an error in the wiring of the instrument, or you may have a poor solder connection. If you have trouble calibrating the tvom, read the following before writing to us.

If you get no meter reading whatever, check to be sure that the two meter terminal nuts are tight and that the 9-volt battery is good. Check to be certain you have installed the two transistors correctly as well as the leads from the two slide switches. Check all soldered connections and if you are in doubt about any of them, reheat with your soldering iron and resolder. Beware of letting solder run over from one terminal to another, particularly in the area around the 1% resistors.

After checking your soldered connections, attempt to balance and calibrate the tvom again. If you still have no success, go back to the beginning of the manual and check your work in each assembly stage with the various figures. Be certain always that the correct part was installed in the correct position on the circuit board.

If you still cannot get your tvom to operate satisfactorily, write to us on a Consultation Sheet, giving full details of how the tvom behaves, and the results you obtained when you attempted to calibrate the instrument, and the results of any tests you may have made (such as the battery voltage). Be sure to give us enough information so that we will have a clear picture of your difficulty and can help you get your tvom in proper operating condition.

When you have your tvom operating properly, you are ready to go ahead with your second set of experiments.

Instructions for Performing the Experiments

The experiments in this manual and in the following ones will familiarize you with the mechanical operation of your tvom -- how to set the knobs, read the scales, and connect the test leads. At the same time, you will learn the causes of incorrect voltage and resistance measurements in electronic circuits.

You are now ready to begin learning how to troubleshoot with a tvom. Remember, taking measurements is only the beginning; it is what you can do with the results of your measurements that counts.

You cannot get a better tvom of the service type than your CONAR Model 212 TVOM. It was designed by service engineers for the service expert. Learn to use it understandingly, and it will be your most powerful tool. It will give you information quickly and accurately; your regular lessons and these experiments teach you what to do with this information.

The parts to be used in the experiments are listed in the parts list on page 3. You should have checked them when you checked your other parts.

In doing the experiments in this manual, you will also use some of the parts left over from Kit 1. All of the parts you will need for each experiment will be listed at the start of the Experimental Procedure for each experiment.

In carrying out your experiments, be sure to follow these steps:

1. Read the entire experiment, paying particular attention to the discussion of the experiment.

2. Carry out the experimental procedure, and perform each step of the experiment exactly as directed. Record

your results in the charts or tables provided for that purpose.

3. Study the discussion of the experiment and analyze your results. If they do not seem to be right, repeat the measurements to make sure you did not make a mistake. Do not go ahead with the next experiment until you get the desired results.

4. Follow the instructions for carrying out the Statement that accompanies each experiment. Fill in the correct answer in the blank space provided at the end of each experiment, and again on the Report Sheet you received with this manual.

You will notice instructions to turn off the tvom at the end of many of the experiments. However, it is not necessary to turn off the instrument if you are going to perform more than one experiment without stopping. These instructions were given as a reminder, and they should be used as such. When you have performed all of the experiments that you are going to do at one time, then turn off the tvom.

WARNING

Failure to follow the instructions given in the experiments may result in serious damage to your meter. Be sure that you carefully read and fully understand the instructions before proceeding with the experiments.

EXPERIMENT 11

Purpose: To show that the tvom will give more accurate readings than the 1000 ohms-per-volt meter in high-resistance circuits.

Introductory Discussion: The sensitivity of a voltmeter consisting of a current meter with a series multiplier resistor is given in ohms-per-volt. This is necessary because the meter usually has several different ranges, and the technician needs to know the total meter resistance he is connecting across the voltage source being measured. To determine the resistance, multiply the ohms-per-volt rating by the full-scale value for the particular range being used.

In the 3-volt meter you constructed in Kit 1, the sensitivity was 5000 ohms-per-volt; the total meter resistance was 3 X 5000, or 15,000 ohms. If the meter range had been extended to 30 volts, a 150,000-ohm multiplier resistor would have been used, and the total meter resistance would have been 150,000 ohms. These figures are true regardless of the amount of voltage being measured on a particular range.

A tvom uses a voltage divider; a switch mechanism is used to connect the input of the bridge circuit to the proper point on the divider for the scale in use. The bridge circuit must be adjusted, or balanced, so that when no voltage is applied to the input, the meter reads zero, regardless of the setting of the voltage divider.

In your tvom, approximately 1 volt is used to give maximum meter deflection. If you are using the 1200-volt range, the selector switch connects the input of the bridge to the lowest tap on the divider; and although 1200 volts is applied to the probes, only 1 volt is applied to the bridge. The same thing happens with the lower ranges. The selector switch connects the bridge to the proper tap on the divider for the range in use, and when maximum voltage for that range is measured, 1 volt is fed to the bridge.

Because of this arrangement, the resistance across the source being measured is always constant, and for this reason transistor voltmeters are not rated in ohms-per-volt. Instead, they are rated according to the voltage-divider network resistance, which is called the input resistance. In your tvom, the input resistance is approximately 12.2 megohms. When you make a measurement, you are connecting 12.2 megohms across the source being measured. Since this is such a very high resistance, the original circuit values in a low-resistance circuit change only slightly, and you measure the true operating voltages. Only in extremely high resistance circuits will there be an appreciable change, and then the measured values will be somewhat different from the true values that exist when the voltmeter is not connected.

Experimental Procedure: In this experiment, in addition to your experimental chassis and tvom, you will need:

- **1 500K potentiometer with switch**
- **1 Potentiometer mounting bracket**
- **1 6-32 hex nut**
- **2 10-megohm resistors**
- **1 1/4" X 6-32 screw**

Turn the tvom "on" and set the function switch to dc, the polarity switch to normal.

In the first part of this experiment you will repeat the measurements made in Experiment 10 of Kit 1, using your completed tvom instead of the 5,000 ohms-per-volt meter of Kit 1. The experimental chassis used in Kit 1 should still have the two 1.5-volt flashlight cells, the three terminal strips and the three series connected resistors in place, as shown in Fig. 11-1.

Install the potentiometer mounting bracket at hole W, using a 1/4" X 6-32 screw and a 6-32 nut. Then install the 500K-ohm potentiometer with on-off switch (PO65) in the potentiometer mounting bracket. Position as shown, attach a control nut and tighten.

Terminals 19 and 20, on the back of the potentiometer, are the on-off switch terminals. Terminals 16, 17 and 18 are the potentiometer terminals.

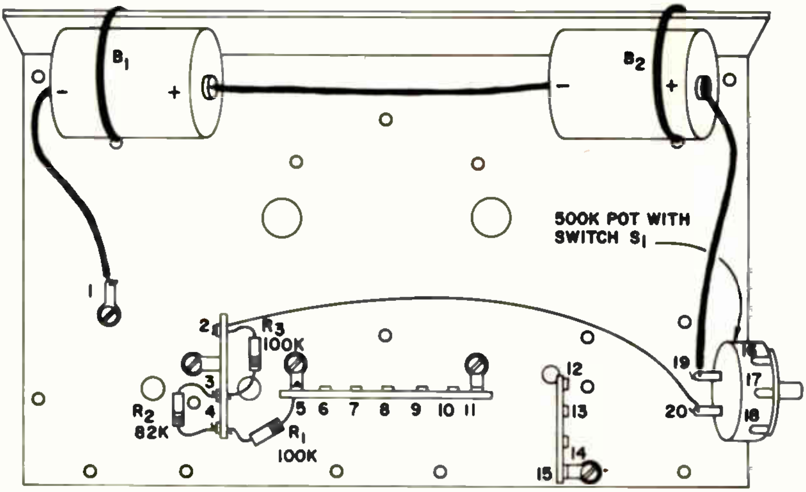


Fig. 11-1. Circuit for Experiment 11.

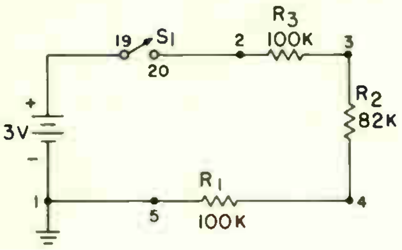


Fig. 11-2. Schematic diagram of circuit for Experiment 11.

Turn the shaft of the potentiometer fully counterclockwise to insure that the switch is off. Then, proceed to wire the circuit shown in Figs. 11-1 and 11-2. Solder the lead from the + terminal of the 3-volt battery to terminal 19 of the on-off switch. Disconnect the negative battery lead from terminal 6 and solder it to the solder lug, terminal 1. Disconnect the lead of the 100K-ohm resistor from terminal 6 and solder it to terminal 5. Finally, connect a length of hookup wire from terminal 2 to terminal 20 of the on-off switch.

The circuit becomes a complete series circuit when you turn the switch on, the return path from the 100K-ohm resistor, R_1, to the negative battery terminal being made through the chassis (ground) from terminal 5 to terminal 1. This arrangement of using the chassis as part of the circuit is quite common and will be used frequently from now on in your experiments.

Step 1: To measure the source voltage.

Clip the "ground" test lead of the tvom to the chassis. Touch the probe of the tvom to the positive battery terminal, and read the meter on the 3.0-volt dc scale. This is the scale you used in the experiments in your first kit. Record the reading in the space provided opposite Step 1 in Fig. 11-3. This may be slightly over 3 volts. If so, mark the value 3+.

Step 2: To measure the voltage across R_1.

Turn on switch S_1 by rotating the potentiometer shaft clockwise. With the ground lead of the tvom still connected to the chassis, touch the probe to the junction of the 100K-ohm and 82K-ohm resistor leads, terminal 4. Observe your reading on the 3-volt dc scale, and record it in the space provided for Step 2 in Fig. 11-3.

Step 3: To measure the voltage across R_2.

Move the ground lead of the tvom to terminal 4 and touch the probe to terminal 3. Record the voltage measured across resistor R_2 beside Step 3 in Fig. 11-3.

Step 4: To measure the voltage across R_3.

Move the ground lead of the tvom to terminal 3 and touch the probe to termi-

STEP	READING
1	2.99
2	1.08
3	.85
4	1.25

Fig. 11-3. Record your readings for Experiment 11 here.

nal 2. Again read the voltage on the 3-volt dc scale, and record your reading in the space provided in Fig. 11-3. Turn off switch S_1.

Discussion: Since the circuit in Fig. 11-2 is exactly the same as the circuit you constructed in Experiment 10, the voltage distribution across the resistors is the same. You should have noticed, however, that the measured values in Experiment 11 are considerably different from those you measured in Step 2 of Experiment 10. When you connected the tvom across a resistor, the resistance value in that part of the circuit did not change appreciably, because the parallel resistance of the tvom was extremely high compared to the value of the resistor.

With the 15,000-ohm meter resistance connected across a resistor, the resistance value was lowered, which changed the entire voltage distribution throughout the circuit while the meter was connected.

The readings you recorded in Fig. 11-3 are for all practical purposes the same as the voltage drops across the resistors with the meter disconnected. If you add them, they will be quite close to the source voltage you measured in Step 1.

This means that in measuring voltages in fairly high resistance circuits, the meter will not affect the voltage appreciably, and you will get an accurate idea of the true operating conditions.

In service work, the fact that the measured value may be slightly lower than the actual value is relatively unimportant. Many manufacturers of electronic equipment list the voltages that should be measured with a tvom. These may be taken as the actual operating values, and variations above and below normal indicate trouble that should be located and corrected.

You have used the tvom just as you did the 5,000 ohms-per-volt meter; you connected the positive meter probe to the end of the resistor nearest the positive battery terminal and the ground lead to the end of the resistor nearest the negative battery terminal.

Because you have a reversing switch on the meter, you could have put the selector switch in the reverse position and connected the ground terminal of the tvom to the positive terminal of the battery and the hot probe to the junction of resistors R_2 and R_3, moving around the circuit in the opposite way. The results would have been almost identical with those taken with the switch in the positive voltage position.

In later experiments, you will see just how the positive and negative dc voltage settings of the polarity switch are used.

Instructions for Statement No. 11: Although, as we have shown, the sensitivity of the tvom is far superior to that of the 5,000 ohms-per-volt meter, you should remember that the tvom does have a definite amount of resistance, and under some conditions can upset the operating voltages.

To obtain data for your statement, solder one lead of a 10-megohm resistor to terminal 2 of Fig. 11-1. Solder one lead of the other 10-megohm resistor to terminal 1 (ground) of Fig. 11-1. Now tack-solder the free ends of the two resistors together to form a 20-megohm voltage divider.

Clip the ground lead of your tvom to the chassis and measure the battery voltage at terminal 19. Enter this value in Fig.

SOURCE VOLTAGE	2.99
VOLTAGE ACROSS FIRST 10 MEG RESISTOR	1.06
VOLTAGE ACROSS SECOND 10 MEG RESISTOR	1.05
SUM OF VOLTAGES ACROSS THE TWO 10 MEG RESISTORS	2.11

Fig. 11-4. Record your readings for the Statement for Experiment 11 here.

11-4 on the top line. Turn S_1 on and measure the voltage at the junction of the two 10-megohm resistors. Enter this value on the second line of Fig. 11-4. Finally, reconnect your tvom to read the voltage across the other 10-megohm resistor and enter your reading on the third line of Fig. 11-4. Now add the voltages across the two resistors and compare this sum with the battery voltage.

Turn off S_1 and your tvom and unsolder and remove all 5 resistors.

Answer the Report Statement here and on the Report Sheet.

Statement No. 11: I found that the sum of the voltages across the two 10-megohm resistors was:

(1) greater than
[✓ *(2)*] *less than*
(3) approximately equal to

the voltage measured across the battery terminals.

EXPERIMENT 12

Purpose: To show that a certain point in a circuit may be positive with respect to one point, and negative with respect to another point.

Introductory Discussion: Many of the expressions used in radio and TV servicing do not seem to have any sensible meaning to the beginner until he uses them himself in practical work.

One expression that causes confusion is "positive or negative with respect to". This means that a point in a circuit is at a positive or negative potential if the voltmeter probes are touched to it and to some other point in the circuit.

For example, we may say that the plate of a tube is 250 volts positive. This statement has no real meaning since a point by itself cannot have a voltage. Voltage means a potential difference between two points. Thus, when we say there is 250 volts on the plate of a tube, we mean there is a potential difference of 250 volts between the plate and the cathode. Another way of saying this is that the plate is positive with respect to, or with regard to, the cathode.

It follows that if the plate is positive with respect to the cathode, the cathode is negative with respect to the plate. At the same time, the grid may be negative with respect to the cathode or, what is the same thing, the cathode may be positive with respect to the grid.

Thus, the cathode can be both positive and negative at the same time, depending on the reference points we have in mind.

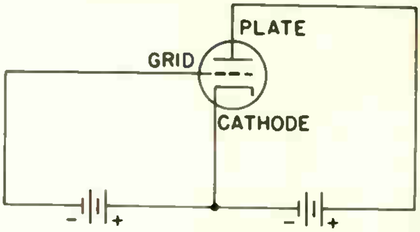


Fig. 12-1. A typical triode tube with batteries for the plate-to-cathode and grid-to-cathode supplies.

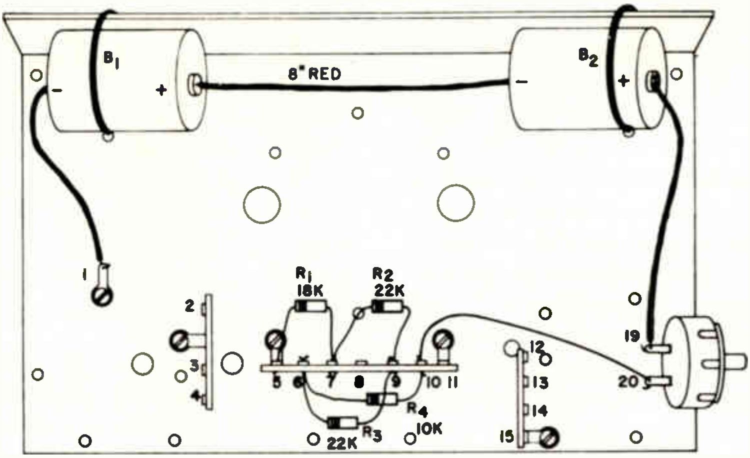


Fig. 12-2. Circuit for Experiment 12.

Fig. 12-1 shows a typical triode tube with batteries for the grid-to-cathode and plate-to-cathode supplies. When the voltage between the grid and the cathode is measured, the positive meter probe should be connected to the cathode, and the negative probe should be connected to the grid. When the plate-to-cathode voltage is measured, the negative meter probe should be connected to the cathode, and the positive probe to the plate. From this you can see that the cathode can be either positive or negative, depending on whether we are referring to the cathode and the grid or to the cathode and the plate. In later kits we will measure grid-to-cathode and plate-to-cathode voltages many times in actual tube circuits.

In this experiment, however, we will use resistors and our 3-volt battery supply. Just remember that a plate or any other point cannot correctly be called positive or negative by itself.

Experimental Procedure: To perform the experiment, in addition to your tvom, you will need the experimental chassis with parts previously installed and:

1 18K-ohm resistor
2 22K-ohm resistors
1 10K-ohm resistor

For this experiment, you will construct the circuit shown in Fig. 12-2. The schematic of this circuit is shown in Fig. 12-3. Connect an 18K-ohm resistor from terminal 5 to terminal 7, connect a 22K-ohm resistor from terminal 7 to terminal 9, connect a 22K-ohm resistor between terminals 6 and 9 and connect a 10K-ohm resistor from terminal 6 to

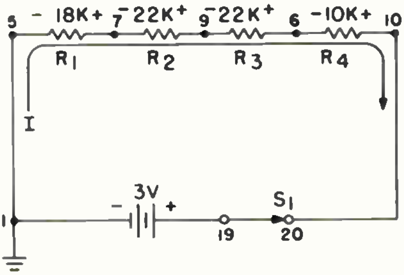


Fig. 12-3. Schematic diagram of the circuit used in Experiment 12.

terminal 10. Disconnect the length of hookup wire from terminal 2 and connect it to terminal 10. Solder all connections.

Fig. 12-3 is a schematic of the circuit you have just constructed. With S_1 closed, a current I will flow as indicated in Fig. 12-3. You know that current goes from minus to plus through a resistor, therefore we have indicated the polarity of the voltage appearing across each resistor in the divider. The left end of each resistor is negative with respect to the right end. It is this fact that you will establish in this experiment.

With your tvom in the dc position and the polarity switch in the normal position, the ground lead is the negative meter lead, while the probe is the positive lead. When the ground lead is connected to one point and the probe is connected to a second point that is positive with respect to the first point, the meter will read upscale in a normal manner. If the probe is connected to a point that is negative with respect to the point to which the ground lead is connected, the meter pointer will move downscale, to the left of zero.

To prove this, turn the tvom on and zero it, and then turn S_1 on. With the tvom set to dc, normal, clip the ground lead of the meter to the chassis and touch the probe to the positive terminal of the battery. The meter will read upscale. Now connect the meter ground lead to the positive terminal of the battery and momentarily touch the probe to the chassis. Note that the meter pointer deflects sharply downscale, to the left past zero, showing that the meter probe is negative with respect to the ground lead.

Step 1: To show that terminal 5 is negative with respect to terminal 7.

GROUND LEAD TO	PROBE TO	UP-SCALE	DOWN-SCALE
CHASSIS	7	✓	
7	CHASSIS		✓
7	9	✓	
9	7		✓
9	6	✓	
6	9		✓

Fig. 12-4. For each step, make a check in the proper box to indicate whether your meter pointer moves upscale or downscale.

Connect the ground lead of the tvom to the chassis, and the probe to terminal 7. Make a check mark in the proper box in Fig. 12-4 to indicate whether the meter pointer moves upscale or downscale. We will not record the exact readings since they are not important in this part of the experiment.

Now reverse the connections of the tvom by connecting the ground lead to terminal 7, and the probe to the chassis. Record the meter pointer movement in the space provided in Fig. 12-4.

An upscale reading on the meter indicates that the meter is connected with the proper polarity. A downscale reading means that the meter is connected with the wrong polarity. Since the meter reading was upscale when the negative lead was connected to the chassis and downscale when the negative lead was connected to terminal 7, the chassis must be negative with respect to terminal 7.

Step 2: To show whether terminal 7 is positive or negative with respect to terminal 9.

Connect the ground lead of the tvom

to terminal 7 and touch the probe to terminal 9. Record the direction of the meter pointer movement in Fig. 12-4.

Connect the ground lead of the tvom to terminal 9, and touch the probe to terminal 7. Again record the meter pointer indication.

Step 3: To show whether terminal 9 is positive or negative with respect to terminal 6.

Connect the ground clip to terminal 9 and touch the probe to terminal 6, and record the meter pointer indication.

Connect the ground clip to terminal 6 and touch the probe to terminal 9, and again record the indication. Open the circuit temporarily by turning S_1 off.

Discussion: If your experiment was conducted successfully, you should have had upscale readings on the first, third, and fifth measurements, and downscale readings on the others. This means that the chassis is negative with respect to terminal 7, terminal 7 is negative with respect to terminal 9, and terminal 9 is negative with respect to terminal 6.

You will notice that terminal 7 is positive with respect to the chassis. However, terminal 7 is negative with respect to terminal 9.

We can also say that terminal 9 is positive with respect to terminal 7 and negative with respect to terminal 6.

Thus, in a series circuit consisting of two or more parts, one point may be either positive or negative, depending upon what other point it is compared with.

In this experiment, we have left the function switch in the dc position and the polarity switch in the normal position, making the ground clip of the tvom the negative terminal and the probe the positive terminal. The probes had to be connected in a certain way in order to give an upscale reading.

In actual practice, this is not done. The function switch is placed in the dc position and the polarity switch is set to normal or reverse -- whichever one will give an upscale reading -- and by looking at the polarity switch you can tell whether the voltage at the probe is positive or negative with respect to the ground clip reference point. You will do this many times in later experiments.

For the present, remember that when we speak of a point as positive or negative, we mean with respect to another point. On a plate, we mean with respect to the cathode of the tube.

Instructions for Statement No. 12: To answer the Statement, we will make use of the polarity switch of the tvom to get an upscale reading and to show that terminal 9 in Fig. 12-3 can be positive with respect to the chassis and negative with respect to terminal 10.

Turn on S_1, and connect the ground clip of the tvom to terminal 9. Touch the probe to the chassis. If the meter reads downscale, slide the polarity switch to the reverse position, and record the actual voltage reading between terminal 9 and the chassis in volts on the margin of this page. Now touch the probe to terminal 10, reset the polarity switch for an upscale reading, and again record the actual voltage measured on the margin of this page. Turn off S_1 and answer Statement 12.

-1.2

~~[illegible]~~

+1.36

Statement No. 12: I found that the polarity of the voltage at terminal 9 with respect to the chassis was:

[✓ *(1) positive*]
(2) negative

and the value was

[✓ *(1) greater than*]
(2) less than
(3) the same as

that measured from terminal 9 to terminal 10.

EXPERIMENT 13

Purpose: To show that a change in the resistance of one part of a series circuit will cause a change in the voltage drops across all of the series-connected parts.

Introductory Discussion: This experiment proves one of the basic facts that you as a technician will use time and again in your work.

The way a set is working may lead you to suspect that the voltage is too low at some point in a circuit or perhaps the voltage is too high at some point. You will use your tvom to see if the voltage is too high or too low. Then, you will look at the circuit diagram to see what could have happened to cause the abnormal readings. After deciding what the probable cause is, you will check the part you suspect of causing the trouble. Your regular lessons and your work on these kits will teach you to do this.

Let us take an example. Suppose you have a voltage divider with the correct source voltage applied to it. What will cause the voltage drop to be too high across some sections of the divider and too low across others?

Ohm's Law (E = I × R) gives the answer. If the voltage E is lower than expected, then I, the current through the part, or R, the resistance of the part, has decreased. You would look for a change in the resistance of the part or for some defect in another part that has decreased the circuit current.

If the voltage is higher than expected, you know that I or R has increased. In this case, you would check for an increase in the part resistance or for a decrease in resistance elsewhere in the circuit that would increase current flow through the entire circuit.

In this experiment you will demonstrate these facts so you will know what to look for when you find similar abnormal voltage readings in your maintenance work.

Remember, it is not enough to know how to take readings -- the important thing is to know what to do with the results of your readings.

Experimental Procedure: In this experiment you will use your tvom and the parts already in place on your experimental chassis.

To construct the circuit in Fig. 13-1, remove the 10K resistor, R_4, from terminals 6 and 10 and resolder the resistor

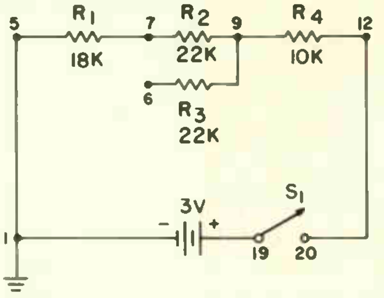


Fig. 13-1. This is the first circuit you will use in Experiment 13.

from terminal 9 to terminal 12. Terminal 12 is on the strip near the switch, S_1. Disconnect the switch lead from terminal 10 and connect it to terminal 12.

After you have constructed the divider circuit of Fig. 13-1, turn on S_1 and set your tvom to read dc normal.

Step 1: To measure the voltages in the circuit.

To measure the source voltage, connect the ground clip of your tvom to the chassis, and the probe to terminal 12. Read your meter on the 3-volt scale and record your reading in Fig. 13-2 in the column for normal resistance (the first blank column) beside "source."

VOLTAGE MEASURED ACROSS	RESISTANCE NORMAL	R_2 DECREASED	R_4 INCREASED
SOURCE	3+	3+	3+
R_1	1.05	1.34	.8
R_2	1.37	.93	1.05
R_4	.56	.72	1.15
	2.98	2.99	3.00

Fig. 13-2. Record your readings for Experiment 13 here.

To measure the voltage across R_1, move the probe to terminal 7. Record your reading beside R_1 in the first blank column of Fig. 13-2.

To measure the voltage across R_2, move the ground clip to terminal 7 and the probe to terminal 9. Record your reading beside R_2 in Fig. 13-2.

To measure the voltage across R_4, move the ground clip to terminal 9 and the probe to terminal 12. Again record your reading in Fig. 13-2.

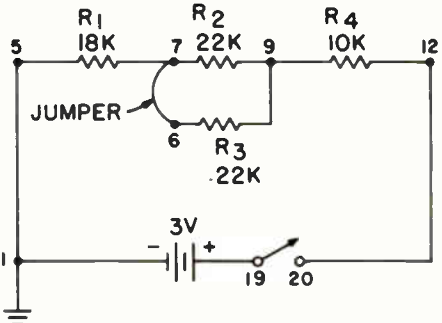


Fig. 13-3. Circuit for Step 2.

Step 2: To show that decreasing the resistance of one section of a voltage divider reduces the voltage drop across that section, and increases the voltage drop across the other sections.

You are to decrease the resistance of R_2 by adding another 22K-ohm resistor in parallel with it, as shown in Fig. 13-3.

To do this, simply solder a short jumper wire from terminal 6 to terminal 7 as indicated in Fig. 13-3.

As you have learned, the resistance of two equal resistors in parallel is equal to half the resistance of one alone. Therefore, we now have 11,000 ohms for R_2 and R_3 in parallel instead of 22,000.

Measure the voltages as you did in Step 1, and record your readings in Fig. 13-2 in the column for decreased resistance in R_2.

Step 3: To show that increasing the resistance of one section of a voltage divider increases the voltage drop across that section, and decreases the voltage drop across the other section.

Rewire the circuit as shown in Fig. 13-4. To do this, remove the jumper from between terminal 6 and terminal 7 and unsolder the switch lead from terminal

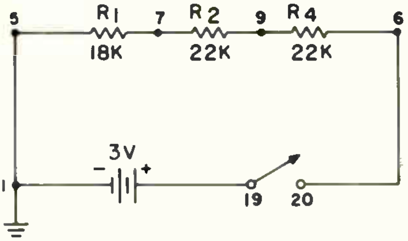


Fig. 13-4. Circuit for Step 3.

12. Resolder this lead to terminal 6 to complete the circuit of Fig. 13-4. The 22K-ohm resistor is now R_4.

Again measure the source voltage and the voltages across R_1, R_2, and R_4 as you did in Steps 1 and 2. Record your readings in Fig. 13-2 in the column for increased resistance of R_4. Turn off switch S_1.

Discussion: Look at the voltages you have recorded in Fig. 13-2. In Step 2, you decreased the resistance of R_2. What happened to the voltage across R_2? It should have decreased. However, the voltage drops across R_1 and R_4 should have increased, since the source voltage is the same, and the sum of the voltage drops is always equal to the source voltage.

Now let us look at the readings for Step 3. Here we increased the resistance of R_4. What happened to the voltage? The voltage across R_4 should have increased. Since the source voltage is still the same and the sum of the voltage drops must equal the source voltage, the other voltage drops should have been lower than they were in Step 1. Here you have seen a practical application of Kirchhoff's voltage law. The sum of the voltage drops in a closed circuit must equal the source voltage. From this we can see that, if the voltage drop across one part in a series circuit changes, the voltage drop across the other components must change in the opposite direction.

There is one thing to keep in mind. Although it is absolutely true that the sum of the voltage drops always equals the source voltage, the sum of the *measured* voltage drops may not exactly equal the source voltage for two reasons.

First, a good servicing type of tvom, such as your CONAR Model 212, has an accuracy of about 5% of the full scale reading. Although more accurate hand-calibrated meters can be made, they are not used in servicing equipment, because such accuracy is not necessary, they are costly, and they cannot stand up under rough treatment. Therefore, measured values can be .15V higher or lower than the true values, indicated on the 3V range (.15 = .05 X 3.0).

Second, you may not be able to read the actual values on the meter. For example, the actual voltage drops across a three-section voltage divider with a 3-volt source might be: .752 volt, 1.527 volts, and .721 volt. The closest you could read these values on your meter would be .75 volt, 1.5 volts, and .7 volt. When you add these, you get 2.95 volts instead of the 3 volts you would actually have. This is close enough. Even if the measured voltages added up to only 2.8 volts, it would be considered entirely normal. A variation of as much as 25% is usually considered normal in most circuits. Thus, if you read your meter scale to the nearest division, the reading will be accurate enough.

Instructions for Statement No. 13: For the Statement, you will use the same circuit used in Step 3. Connect the ground clip of your tvom to terminal 9 and the probe to terminal 6. Turn on S_1

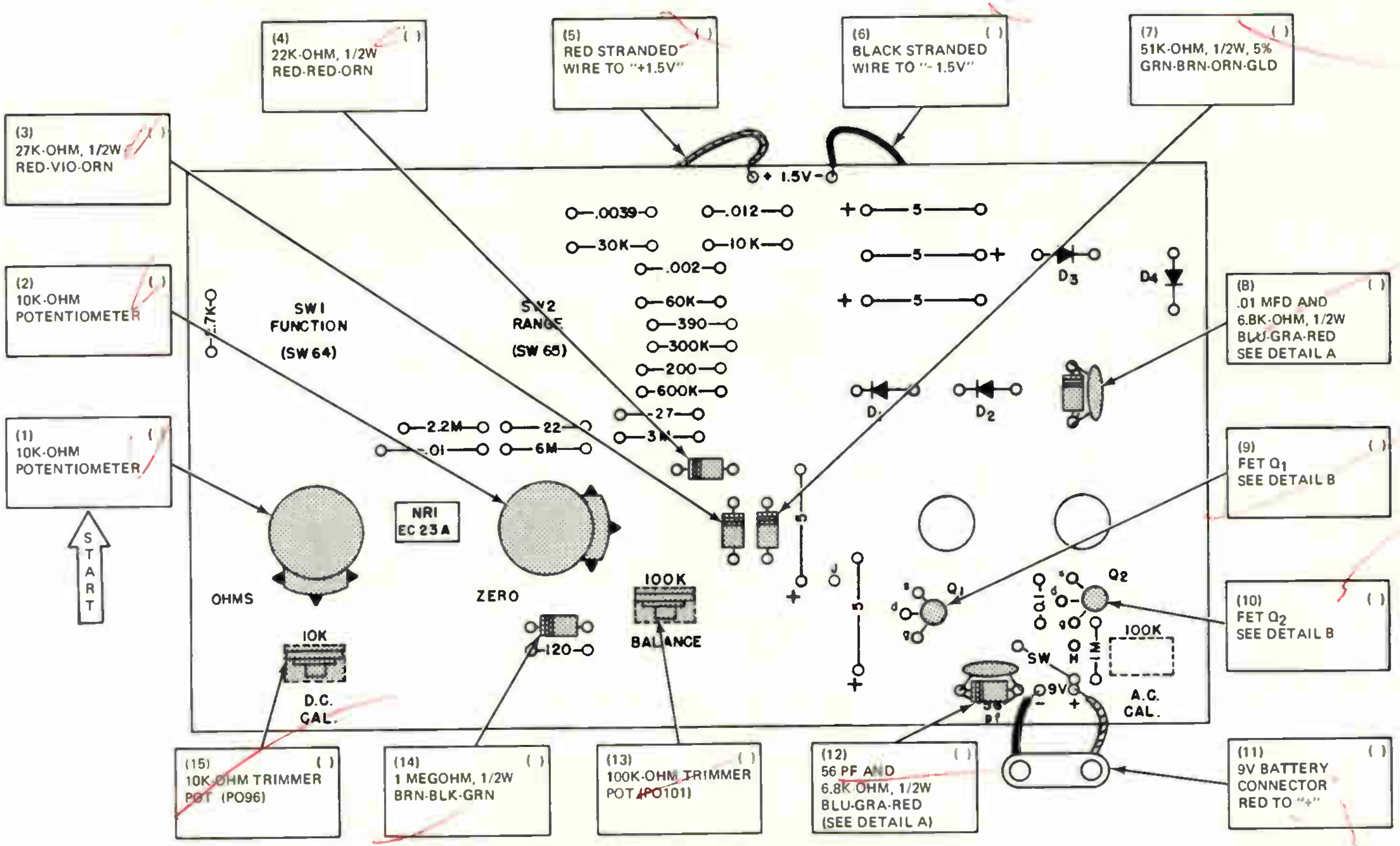


Fig. 2. Stage I Assembly.

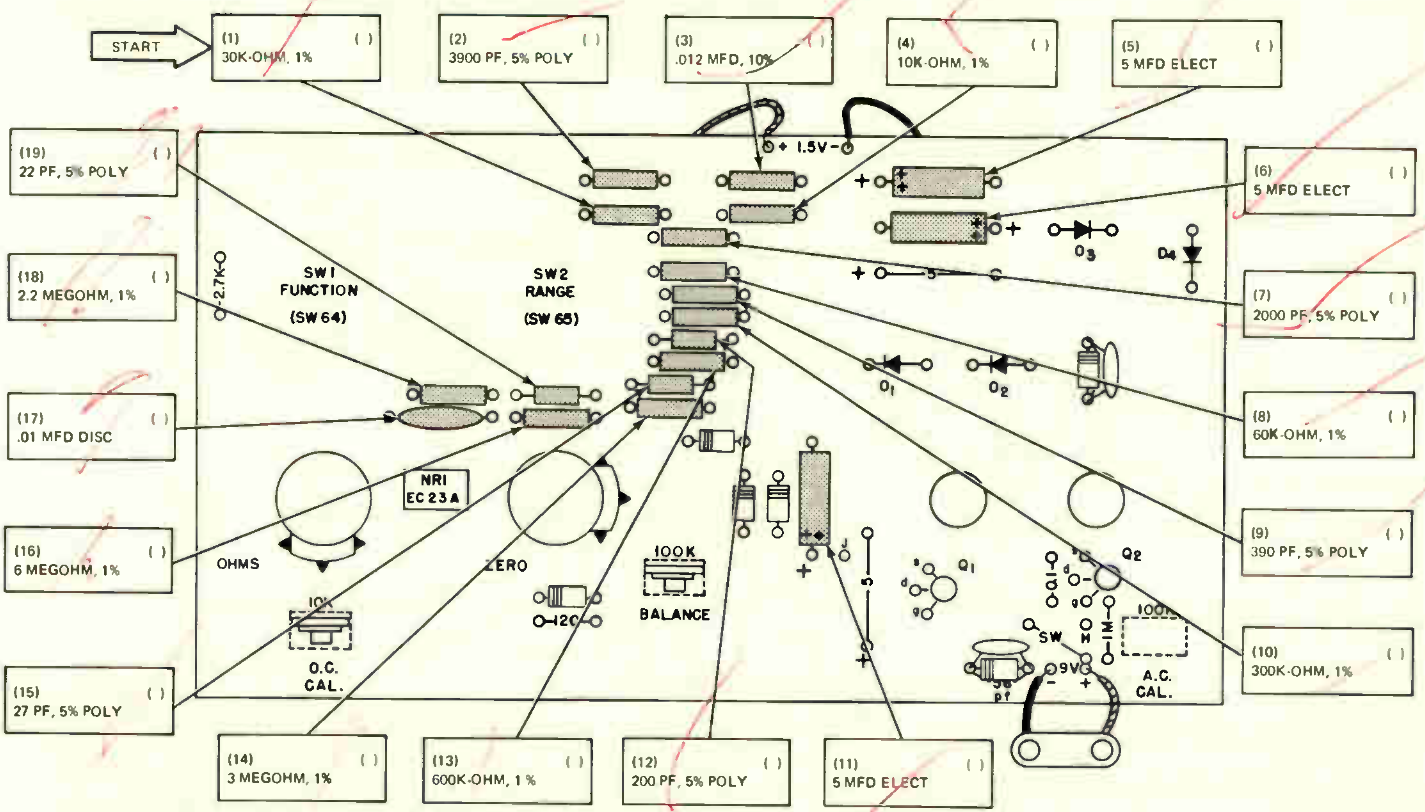


Fig. 3. Stage II Assembly.

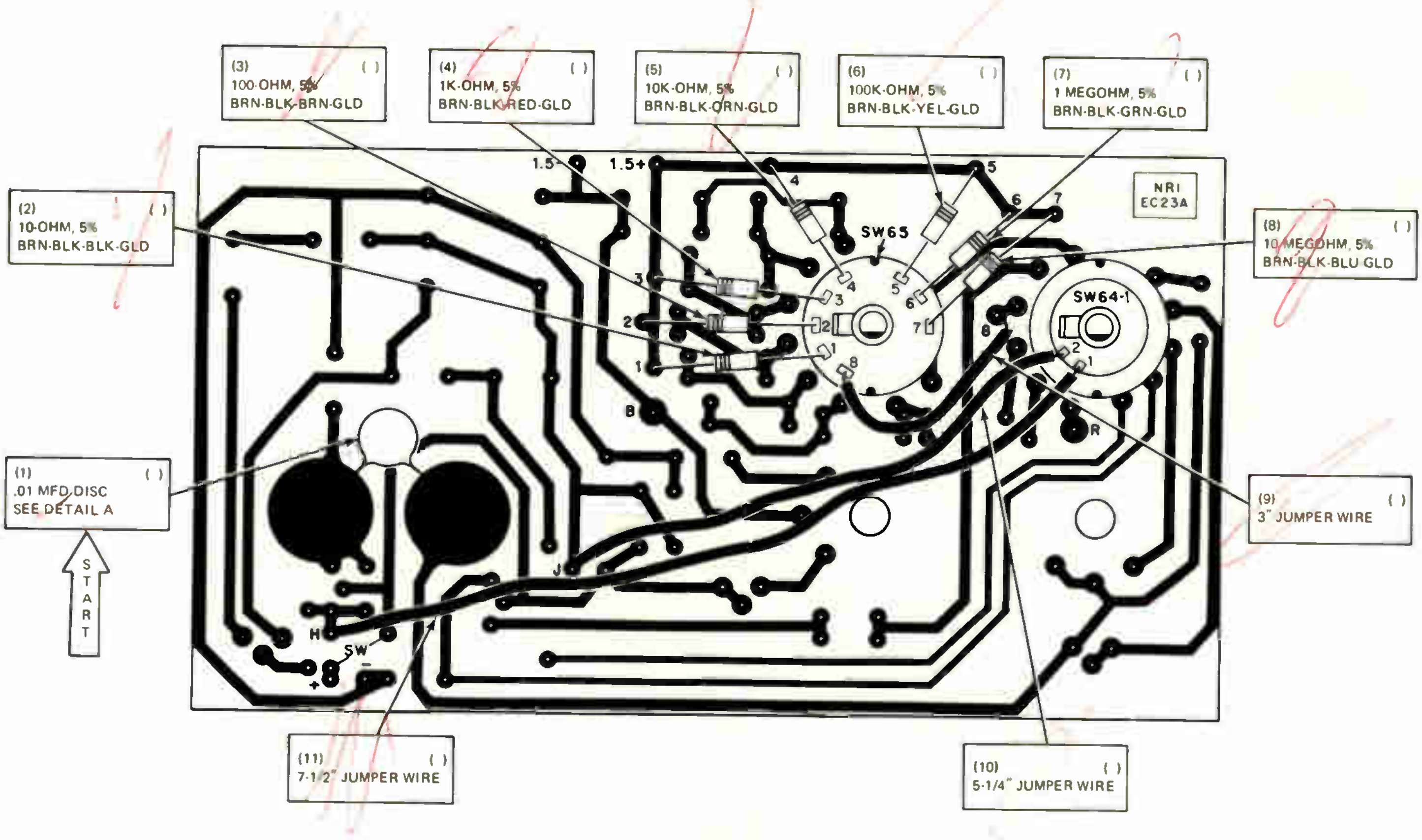
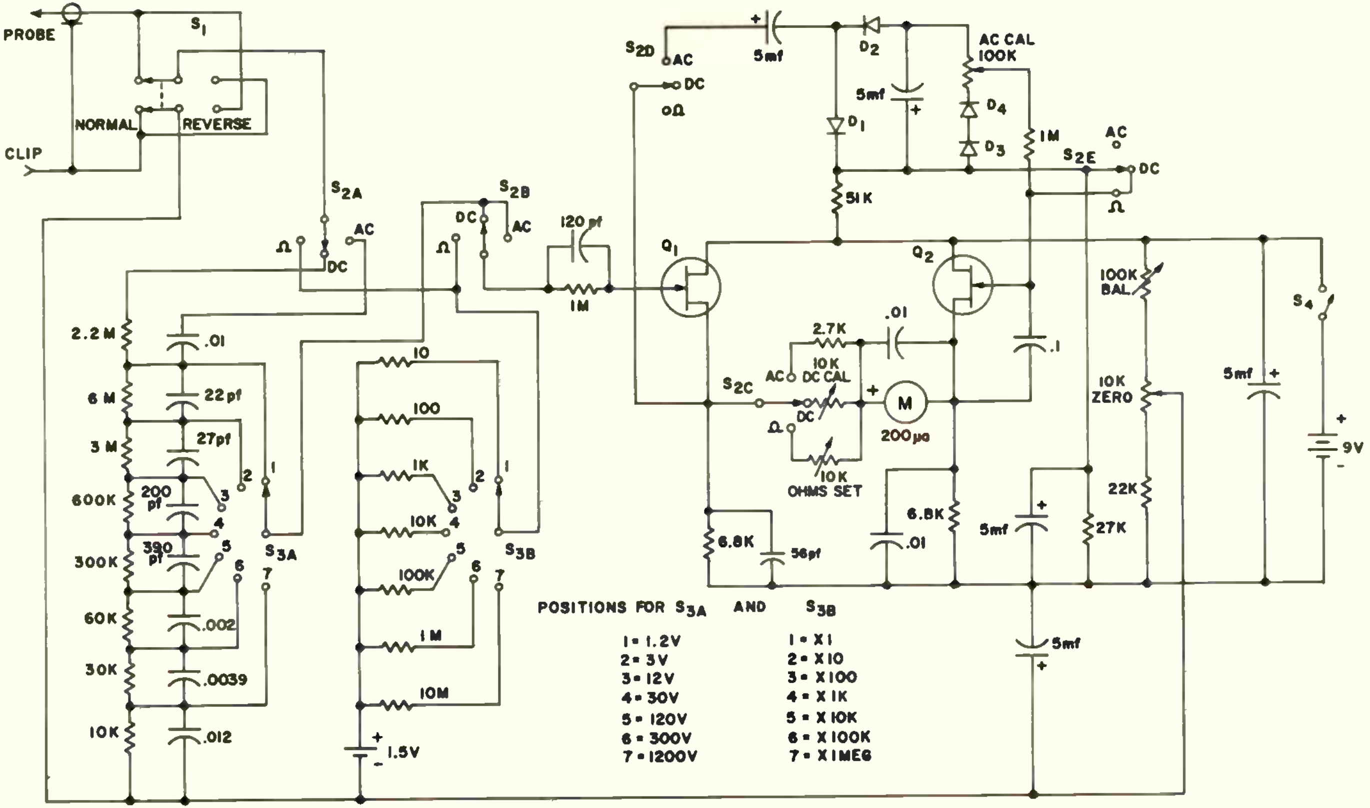


Fig. 4. Stage III Assembly.



POSITIONS FOR S_{3A} AND S_{3B}

S_{3A}	S_{3B}
1 = 1.2V	1 = X1
2 = 3V	2 = X10
3 = 12V	3 = X100
4 = 30V	4 = X1K
5 = 120V	5 = X10K
6 = 300V	6 = X100K
7 = 1200V	7 = X1MEG

Schematic diagram of the Model 212 TVOM.

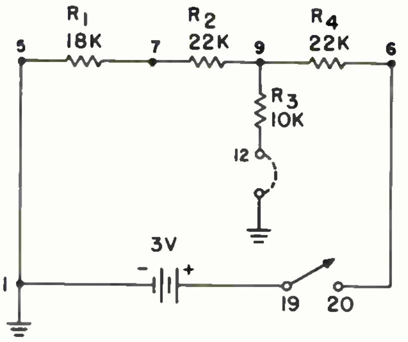


Fig. 13-5. Circuit for Statement 13.

and note the reading in the margin of this page. 1.14

For the statement you are to see what happens to the voltage across R_4 when you shunt R_1 and R_2 with a 10K-ohm resistor. To do this, simply short terminal 12 to the chassis with a screwdriver or a piece of wire as indicated in Fig. 13-5. Measure the drop across R_4 between terminal 9 and terminal 6 with terminal 12 shorted to the chassis. Compare your two voltage readings, and answer the 2.31 statement here and on the Report Sheet. Turn off your tvom and S_1.

Statement No. 13: When I shunted R_1 and R_2 with a 10K-ohm resistor I found the voltage across R_4:

[✓ *(1) increased.*]
(2) decreased.
(3) remained the same.

EXPERIMENT 14

Purpose: To show the effects of resistance variations in series-type voltage dividers; and to show how the resultant voltage variations can be kept to a minimum by using a resistor, called a bleeder.

Introductory Discussion: As you have seen in preceding experiments, if any resistance in a series circuit is changed in value, the voltage across each resistor changes. In some circuits we will want to have a changing resistance and yet have the voltage remain fairly steady as the resistance changes. The changing resistance is often referred to as a "load".

As you have previously learned, when a large resistor and a small resistor are in parallel, the combined resistance is essentially that of the smaller resistor. This means that even though the larger resistance may vary, it will still be enough higher than the smaller resistance so that the combined resistances will remain essentially the same. This very important fact is put to good use where we wish to stabilize the voltage across a load whose resistance varies. By properly designing the voltage divider, these voltage variations can be kept quite small.

In this experiment you will see how this is done. You will build a circuit in which the load resistance can be varied and in which the load requires considerably less than the source voltage of 3 volts. You will see how the voltage across the load changes when the load resistance is changed. Then, you will change the circuit so that the effects of the variations in a load resistance are reduced to a minimum.

As a technician you will not be particularly interested in being able to design voltage dividers, but you certainly will want to know how they work. If you find that a particular circuit is not operating satisfactorily, you must rely on your voltage measurements to tell you what could have happened in the circuit. A knowledge of how voltage dividers operate will go a long ways.

Experimental Procedure: In this experiment you will need your tvom, most of the parts on the experimental chassis and the following parts:

- **1 220K-ohm resistor**
- **1 470K-ohm resistor**
- **1 Slip-on alligator clip**
- **Hookup wire**

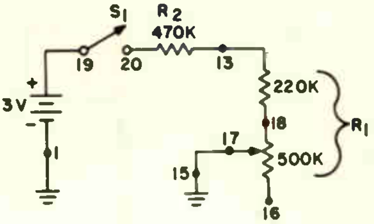


Fig. 14-2. Schematic of the circuit of Step 1.

If you have not done so recently, check the tip of your soldering iron. It may have become covered with the typical black insulating oxide that prevents heat from flowing from the iron to the parts, or the tip may have become pitted. If so, file and retin it as described in Kit 1. Check the tip frequently throughout all your experiments, and don't let it become dirty.

Begin by removing the 22K-ohm resistor connected between terminals 6 and 9 and the 10K-ohm resistor connected between terminals 9 and 12, leaving in place the 18K-ohm and 22K-ohm resistors shown in Fig. 14-1. You may leave the wire from terminal 20 to terminal 6 in place (although it is not shown in Fig. 14-1) as it will be used in later steps of this experiment.

Now construct the circuit shown in Fig. 14-2 and detailed in Fig. 14-1. Terminals 16, 17 and 18 are the three potentiometer terminals.

Slip the alligator clip over the tvom probe as shown in Fig. 14-3 so you can clip both leads of the meter to the circuit under test. It may be necessary to bend down the solder loop in the clip so that the clip will slip easily onto the probe. If the clip is too loose, squeeze the clip with

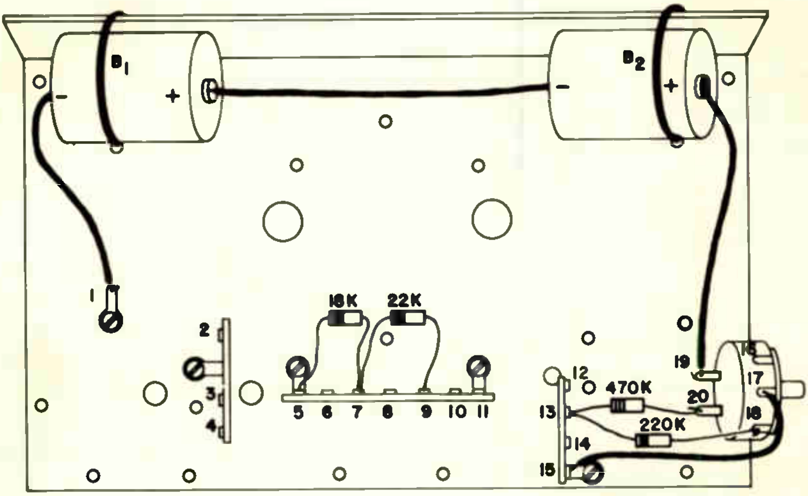


Fig. 14-1. Chassis connections for the circuit of Step 1.

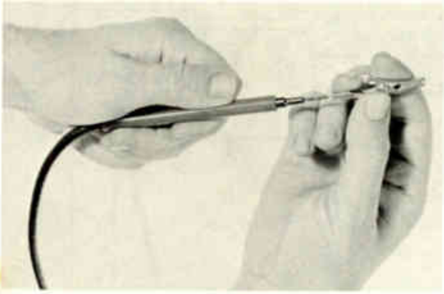


Fig. 14-3. How to slip the alligator clip onto the positive probe.

your combination pliers so it is tightly clamped on the probe tip.

You are now ready to see how the circuit works.

Step 1: To show how a variation in load resistance affects the load voltage.

Clip the ground lead of the tvom to the chassis. Now measure the load voltage by clipping the probe to terminal 13 in Fig. 14-2. In taking measurements, it is sometimes easier to clip it on and leave it there. In this step, it will be easier to clip the lead in place so that you will have both hands free. The meter is now connected across the 220K-ohm resistor and part of the 500K-ohm potentiometer. These two parts make up the load resistor R_1 in Fig. 14-2.

Turn the shaft of the potentiometer clockwise to turn on S_1. Adjust the potentiometer so that the meter reads 1.3 volts. This can be considered to be the normal resistance of R_1.

With the red probe still clipped to terminal 13, turn the potentiometer shaft all the way counterclockwise. This increases the resistance of the load and increases the voltage across the load. This increased load resistance is a smaller load because the circuit draws less current and dissipates less power. Record the voltage across the load at this time in the space provided for voltage with minimum load in Step 1 of Fig. 14-4.

Now rotate the potentiometer shaft fully clockwise, reducing its resistance practically to zero. The load resistance then consists of only the 220K-ohm resistor. This decreased load resistance is a larger or heavier load because the circuit draws more current and dissipates more power. Note the meter reading, and record it in the space for voltage with maximum load in Step 1 of Fig. 14-4.

	VOLTAGE WITH MINIMUM LOAD	VOLTAGE WITH MAXIMUM LOAD
STEP 1	1.52	8.6
STEP 2	1.26	1.22

Fig. 14-4. Record your readings for Experiment 14 here.

Step 2: To show how the load voltage can be kept fairly constant even though the load resistance varies.

Turn S_1 off and remove the 470K-ohm resistor from between terminals 13 and 20. Rewire the circuit to conform to Fig. 14-5. You will need to reconnect and solder the lead from terminal 20 to

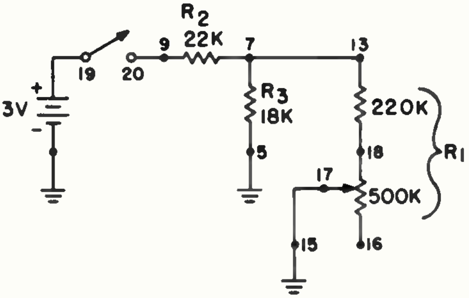


Fig. 14-5. Schematic diagram of circuit used in Step 2.

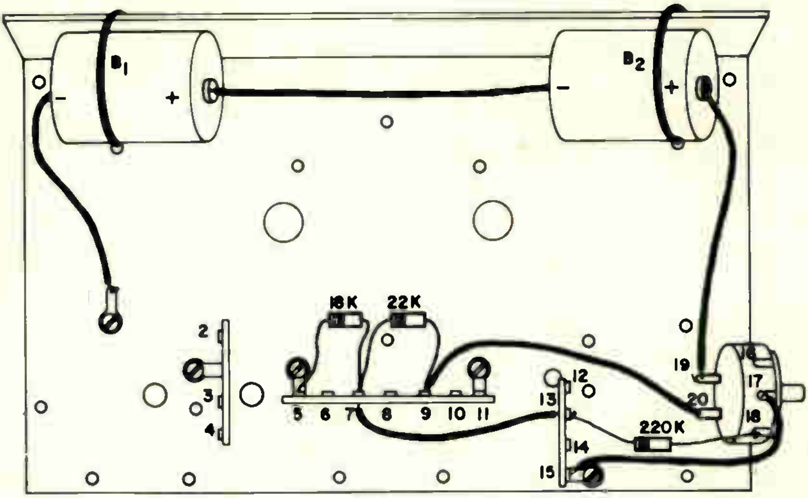


Fig. 14-6. Chassis arrangement for Step 2.

terminal 9, and add a length of wire between terminals 7 and 13 to make these changes as indicated in Fig. 14-6.

Turn S_1 on and adjust the potentiometer shaft fully counterclockwise, and measure the load voltage between the chassis and terminal 13. Record this as the voltage with minimum load for Step 2 in the space provided in Fig. 14-4.

Now turn the potentiometer shaft clockwise as far as it will go to reduce the value of R_1. Record the reading as the voltage with maximum load in Fig. 14-4. Turn off S_1.

Discussion: Look over the figures you have recorded in Fig. 14-4, and compare the two sets of readings. There should be a greater difference between the maximum and minimum voltages in Step 1 than in Step 2.

In any voltage divider, the source voltage divides between the circuit parts, the voltage across a part being proportional to its resistance. If there are two parts having equal resistances, the source voltage will divide equally between them. Both will have the same voltage drop. If one part is variable, some of the time it will have more than half the voltage across it, and some of the time less than half.

In Step 1, the difference between the voltages should have been large, because with the potentiometer set so that none of its resistance was in the circuit, the total load resistance was only 220K ohms -- less than half the 470K-ohm resistance of R_2 -- so there would be much less than half of the source voltage across the load. With the potentiometer set so that its total resistance was in the circuit, the load resistance was 720K ohms -- more than one and a half times the resistance of R_2 -- so there would be much more than half the source voltage across the load. The only time we would have the desired 1.3 volts across the load would be when the potentiometer was set so that the total load resistance of R_1 was slightly less than 470K-ohms.

In Step 2, the voltage difference should have been very small. Here you modified the circuit and put in a bleeder resistor. When two resistors are in parallel, the combined resistance will be less than that of the smaller resistor. Therefore, the combined resistance of R_1 and the 18K-ohm bleeder resistor R_3 in Fig. 14-5 will be less than 18K ohms, whether R_1 is at its maximum of 720K ohms or its minimum of 220K ohms. The combined resistance will vary from about 16.5K ohms to about 17.5K ohms. The voltage will divide almost equally between R_1 and R_2, and, therefore, will always be close to the desired 1.3 volts across R_1.

In your work, be on the lookout for bleeders. They can open or change in value just like any other part, and they must be taken into consideration when the parts with which they are in shunt are checked.

Instructions for Statement No. 14: For this Statement we will simulate a burned-out bleeder resistor R_3 in the circuit shown in Fig. 14-5. Unsolder the 18K-ohm resistor R_3 from terminal 5 and turn on S_1. Measure the voltage across load resistor R_1 by connecting the ground lead of your tvom to the chassis and the probe to terminal 7. Compare the reading you obtain with the voltage reading you have recorded for Step 2 in Fig. 14-4. Answer
2.35 the following Statement and mark your answer on your Report Sheet. Turn off
29.1 S_1 and your tvom, disassemble the circuit and clean the parts. Do not remove the leads from the positive and negative terminals of the 3-volt battery going to terminal 19 and terminal 1.

Statement No. 14: With the 18K-ohm bleeder resistor open, I found that the voltage applied to the load:

[✓ *(1)*] *increased.*
(2) decreased.
(3) remained the same.

EXPERIMENT 15

Purpose: To show that the current flowing in a circuit can be determined by measuring the voltage across a known resistance and applying Ohm's Law.

Introductory Discussion: Ohm's Law tells us that current in amperes is equal to voltage in volts divided by resistance in ohms. Therefore, if we measure the voltage drop across a known resistor, we can accurately determine the current through it by dividing the voltage by the resistance.

In this experiment, you will see that you can determine the current flowing in a circuit by measuring the voltage across any known resistor and applying Ohm's Law. You will also see that you can use the voltmeter scale to indicate current in milliamperes if there is a 1K-ohm resistor in the circuit.

Experimental Procedure: For this experiment, you will need your tvom, the experimental chassis and the following parts:

2	1K-ohm resistors
1	3.3K-ohm resistor

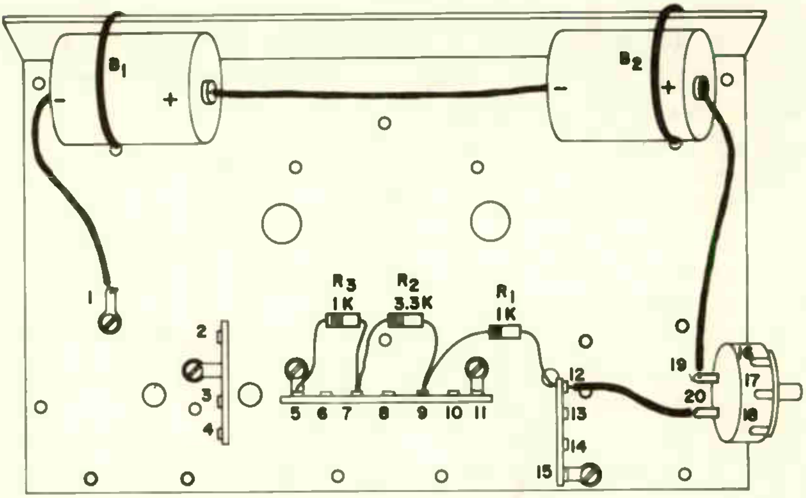


Fig. 15-1. Parts placement for Experiment 15.

First construct the series circuit shown in Fig. 15-1 and shown schematically in Fig. 15-2. Make sure S_1 is off.

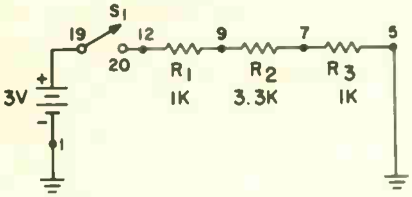


Fig. 15-2. Schematic diagram for the circuit used in Experiment 15.

Step 1: To find the current flowing through the 1K-ohm resistor R_1.

Turn on S_1. Measure the voltage across the 1K-ohm resistor by clipping the ground lead of your tvom to the junction of R_1 and R_2 and touching the probe to terminal 12. Record your reading in Fig. 15-3 in the space for the voltage reading across R_1.

Now, to find the current, we use Ohm's Law, which tells us that the current in amperes is equal to the voltage in volts divided by the resistance in ohms, I = E/R. By substituting the proper numbers for the letters in the formula (1000 for R, and the voltage you have just measured and recorded for E), you can find the current in amperes. To change the answer to milliamperes, we multiply by 1000, moving the decimal point three places to the right.

	VOLTAGE READING	CURRENT IN MA.
R_1 1K	.55v	.55ma.
R_2 3.3K	1.85V	.56ma.
R_3 1K	.57V	.55ma.

Fig. 15-3. Record your readings for Experiment 15 here.

Here is how to figure the current. When we measured the voltage across the 1K-ohm resistor, we obtained a voltage of about 0.6 volt. Using this figure we get:

$$I = E \div R$$

$$I = \frac{0.6}{1000} = .0006 \text{ amp}$$

To change this to milliamperes we multiply by 1000 which gives us:

$$.0006 \times 1000 = .6 \text{ milliamperes}$$

Notice that in performing the operation we simply had to move the decimal point three places to the right.

Now you determine the current through the 1K-ohm resistor from your experimental results. Remember that because of normal parts tolerances, you may not get exactly the same result that we got. Record your current in Fig. 15-3.

Step 2: To find the current through the 3.3K-ohm resistor R_2.

Measure the voltage across R_2 by connecting the tvom with the ground lead to the junction of R_2 and R_3 (terminal 7), and the probe to the junction of R_1 and R_2 (terminal 9). Record the reading in Fig. 15-3. Figure the current through R_2 just as you did for R_1 in Step 1. This time substitute 3300 for R in the formula, and the second voltage measurement for E. Record the current in Fig. 15-3, after multiplying the answer by 1000 to change amperes to milliamperes.

Step 3: To find the current through resistor R_3.

Measure the voltage across R_3 by connecting the ground lead to the chassis and the probe to the junction of R_2 and R_3 (terminal 7). Figure the current as before, again using the last voltage measured for E and 1000 for R. Record this in Fig. 15-3, after multiplying by 1000. Turn off S_1.

Discussion: Now let us compare your results for Steps 1, 2, and 3. The three current values should be approximately the same, because the same current flows through all components in a series circuit. Actually, the current is exactly the same anywhere in the circuit, but because of parts tolerances and the difficulty in reading the meter accurately, your figures may show slight differences.

Notice the voltage value you measured across the 1K-ohm resistor R_1 and the current you calculated for R_1. The number of volts across R_1 and the number of milliamperes flowing through it should be the same, because you divided the voltage by 1000 to find the current, and then multiplied by 1000 to change it to milliamperes. This means that when the resistance equals 1000, the voltage across it in volts is equal to the current through it in milliamperes. Because of this fact, you can read the current directly on the voltmeter scale if you are measuring across a 1K-ohm resistor. If the voltmeter indicates .2 volt, you have .2 milliampere of current. If it indicates 1.5 volts, you have 1.5 milliamperes of current, etc.

If you wanted to measure current with a voltmeter and there was no 1K-ohm resistor in the circuit, you could add a

1K-ohm resistor in series, and measure the voltage across it, provided the resistance already in the circuit is reasonably high so that the addition of the 1K-ohm resistor will not appreciably increase the total resistance in the circuit. However, technicians seldom go to the trouble of inserting a resistor in a circuit so they can read the current value from their voltmeter scale. It takes too long to unsolder leads to install a resistor and then remove the resistor and reconnect the circuit after the measurement has been completed. Also, the busy technician will not use Ohm's Law each time he wants to know something about the current in a circuit. In practical work, you seldom want to know the amount of current. All you want to know is whether the amount is correct, and it will be if the voltage is correct.

Circuit current values are not given for most electronic equipment. However, voltage values are generally given. If the correct voltage drop appears across a part, you can assume that the amount of current is correct for that circuit.

The technician is interested in three possibilities as far as current is concerned. These are:

1. Is the current normal?
2. Is the current too high?
3. Is the current too low?

Voltage measurements give all three answers without the use of Ohm's Law or the necessity of unsoldering and resoldering connections.

Instructions for Statement No. 15: For the statement, you will short out R_3 and determine the current in the series circuit composed of R_1 and R_2. To do this, connect your tvom to read the voltage across R_1, turn on S_1, and short terminal 7 to the chassis with a wire or a screwdriver. Since R_1 is a 1K-ohm resistor, the voltage across it will be equal to the circuit current in milliamperes. Write this value down in the margin of this page. Now turn off S_1 and answer the Report Statement. You will use the circuit already connected for the next experiment, so do not dismantle the experimental chassis.

6.9ma,

Statement No. 15: When I shorted R_3 I found that the circuit current was:

[✓ *(1) greater than*]
(2) less than
(3) the same as

the circuit current measured in Steps 1, 2, and 3.

EXPERIMENT 16

Purpose: To show that continuity can be checked by taking voltage measurements.

Introductory Discussion: The word "continuity" as used in electronics refers to the completeness of the path through which current is to flow. If there is no continuity, in other words, if the path is broken at some point, current cannot flow.

You know from studying your lessons and from the experiments you have already performed, that current flows only in a complete circuit, and that when current flows through a resistance, there is always a voltage drop across the resistance. These two facts are of utmost importance to a technician, because he uses them constantly in troubleshooting.

A complete circuit has a voltage source, connecting wires, and one or more parts through which current can flow. The parts in the circuit do not necessarily have to be resistors -- all parts through which current can flow have some resistance. Examples of these parts are coils, transformers, series tube filaments, and connecting wires. The fact that such parts have some resistance means that there is a voltage drop across each part.

You cannot measure a voltage drop across the connecting wires in a circuit because the resistance of the wire is so close to zero that the voltage drop across it is essentially zero. You can get a pretty good idea of what the voltage drop across each part in a circuit should be by looking at the schematic diagram. For example, if there are three resistors having approximately the same resistance in a series circuit, you should find that the voltage drop across each of the resistors is equal to about one-third of the source voltage. On the other hand, if one very high resistance is in series with one or more low resistances, the voltage drop across the high resistance will be very nearly equal to the source voltage, and the voltage drop across the low resistance will be almost zero.

If there is no voltage drop across one part in a circuit and there is a voltage drop across the other parts, there must be a complete short circuit across the part with no voltage drop. Then the current flows through the short rather than through the part. Since the resistance is essentially zero through the short, there is no voltage drop to measure.

If you measure the full source voltage across a part in a series circuit, you can assume the part is open (will not pass current). The full source voltage across a part indicates there is no voltage across the other parts in the circuit, and no current is flowing through them. The break, as you will prove, is in the part across which you measure the source voltage.

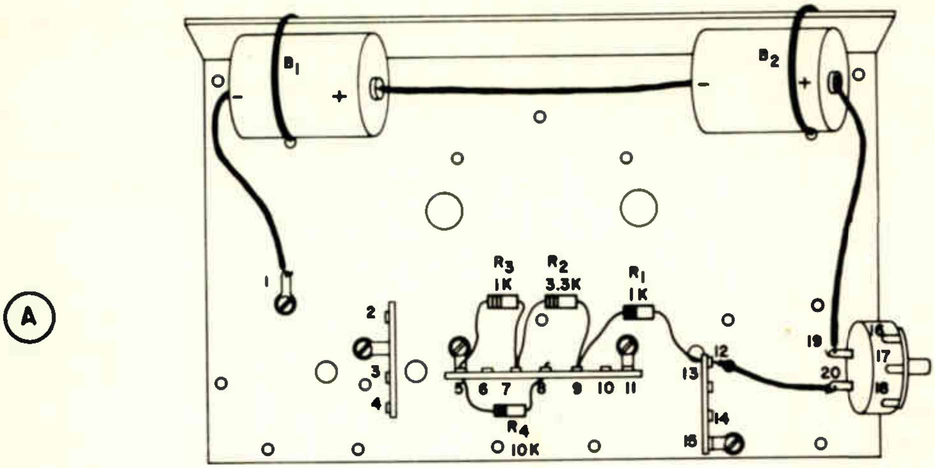
We will investigate these conditions in this experiment so that when you run across them in service work, you will know what to expect.

Here, of course, we are working with low voltages and simple circuits that show only the desired effects. In later kits you will apply the same tests to circuits using the voltage from your power line. You will work with circuits that amplify, that detect, that rectify, and that produce signals of their own. In short, you will learn all you need to know about the circuits.

Experimental Procedure: To perform this experiment you will need the tvom, the circuit you constructed in the last experiment, and the following parts:

1 10K-ohm resistor
1 10-megohm resistor
Hookup wire

For this experiment you will use the circuit shown in Fig. 16-1. As you can see, all you need to do is add the 10K-ohm resistor from terminal 5 to terminal 8 to make the circuit.



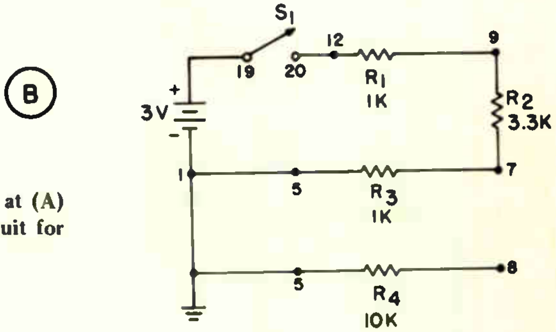


Fig. 16-1. The chassis layout is shown at (A) and the schematic diagram of the circuit for Experiment 16 is shown at (B).

Step 1: To show that there is a voltage drop across each part in a complete circuit.

Examine Fig. 16-1. You can see that there is a complete circuit consisting of R_1, R_2, and R_3 in series across the 3-volt source. Electrons will be pulled through the circuit into the positive terminal of the battery and pushed out into the circuit from the negative terminal of the battery. Electrons cannot be pushed into resistor R_4 because the electrons have no place to go. Unless electrons are removed from terminal 8, none can enter from ground. Since there is no current through this resistor, there will be no voltage drop across it.

Turn on S_1 and clip the negative terminal of your voltmeter to the chassis. Touch the probe to terminal 8. Although there may be a momentary quiver of the meter needle, there will be no steady reading. This shows that there is no voltage drop across R_4. Now touch the probe to terminal 7. Here there will be voltage, which will be less than the source voltage. Touch the probe to terminal 9. You will get a voltage reading greater than the one you measured at terminal 7. Move the probe to terminal 12 and you will measure the full source voltage. This indicates that there is continuity throughout the complete circuit. The fact that the voltage increased from terminal 7 to terminal 9 showed that there was a voltage drop across each part.

Previously, we have measured the voltage across individual resistors. We could have done so in this case, but in actual electronics work you usually make all your measurements with respect to one point in the equipment.

Step 2: To show that the lack of a voltage drop across only one part in a complete circuit shows that that part is shorted.

Cut a piece of hookup wire about two inches long and strip the insulation from it. Solder this lead from terminal 7 to terminal 5. R_3 is now shorted.

With the negative voltmeter lead clipped to the chassis, touch the probe to terminal 7. You should not get a reading because, although current flows through this part of the circuit, there is no appreciable resistance between these points. The current takes the easy path through the bare wire instead of the high resistance path through R_3. Touch the probe to terminal 9; this should give you a reading -- showing that current is flowing through R_2 and also through R_1. Move the probe to terminal 12. You will measure the full source voltage here. Remove the bare wire shorting R_3, and you are ready to go on to the next step.

Step 3: To show that an open part in an otherwise complete circuit has the full source voltage across it and that there are no voltage drops across the other parts.

Fig. 16-2. How to make a dummy open part with two pieces of wire.

Let us assume that R_3 has burned out. Rather than ruin a good resistor, we will make up a dummy part to simulate the effect of an open resistor. To do this, cut two pieces of hookup wire each about 1-1/2 inches long. Remove the insulation from only one end of each wire. Wrap the insulated ends of the wires over each other so you will have an "open part" with two leads. It should look something like Fig. 16-2.

Unsolder R_3 from terminal 7 and solder one lead of the dummy resistor to terminal 5 (leave R_3 and R_4 connected to this point). Solder the other lead of the dummy resistor to terminal 7 and imagine that this is R_3 after it has burned out and become open.

Clip the ground lead of the tvom to the chassis. Touch the probe to terminal 12. You should measure the full source voltage. Now touch the tvom probe to terminal 9. Again you should measure the full source voltage, showing that there is no voltage drop across R_1. Now move the probe to terminal 7. Again you should measure the full source voltage, showing that there is no drop across resistor R_2 and that all of the source voltage is across the dummy open resistor. To further prove that there is no voltage drop across the good parts, connect your ground clip to terminal 7 -- the junction of R_2 and dummy resistor R_3. Touch the probe to terminal 9. Except for a momentary flicker of the meter pointer, you will get no reading. Now move the ground clip to terminal 9 and touch the probe to terminal 12. Again you should get no reading, showing that there is no voltage drop across the parts.

This method of testing across each part individually is a more certain check than measuring from a fixed point such as ground.

Now remove the dummy resistor and resolder the free end of R_3 to terminal 7, completing the original circuit.

Step 4: To show that a check of the source voltage does not indicate the presence of continuity in the circuit connected to it.

Connect the ground clip of the tvom to the chassis. Touch the probe to terminal 19 of switch S_1 in Fig. 16-1. Note the exact reading. Now open the circuit by turning S_1 off. Repeat the measurement by touching the probe again to terminal 19. You will note that there is no difference in voltage at this point whether the circuit is open or closed. Because of this, a check of voltage across a part or across a series of parts directly at the source does not show if current can flow through the circuit or the part. Such a measurement only checks the condition of the voltage supply and not the parts connected to the source.

Step 5: To show that both ends of a part having no voltage drop are at the same potential, and that the continuity of the part can be checked by voltage measurements.

In Step 1 of this experiment, you found that there was no voltage drop across resistor R_4. Let us prove by measurements that terminals 5 and 8 are at the same ground potential. Turn on S_1 and clip the ground lead of your tvom to the chassis, and touch the probe to terminal 8. You will not get a reading. Now clip the ground lead to terminal 8 and touch the probe to the chassis. Again you will not get a reading. With the ground clip on terminal 8, touch the probe to terminal 7. This time there will be a reading. Note its value carefully, and jot it down on the side of the page. Now connect the ground clip to the chassis, and touch the probe to terminal 7. You should measure the same voltage between the chassis and terminal 7 as you did between terminals 8 and 7. Terminals 5 (chassis) and 8 are both negative with respect to terminal 7.

.59

.59

Discussion: The facts that this experiment brings out are of such importance that they are listed here. Refer to this listing whenever you need refreshing on these points. Eventually, you will become so familiar with all of these facts that you will know at once what to look for when you run across similar conditions in your service work.

1. If current can flow through a circuit there will be a voltage drop across all unshorted parts in the circuit.

2. If one part in a complete circuit has no voltage drop across it, but there are voltage drops across all other parts, the one with no voltage drop is shorted. The short may be in the part itself or in some other part shunting it.

3. If in a circuit that should be complete, you find full source voltage across one part and no voltage across the other parts, the part with full source voltage across it is open.

4. If only one part is connected across a source, the presence of voltage across the part is meaningless, since full source voltage will be across it whether or not the part is open.

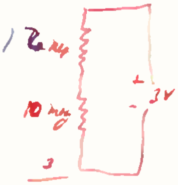
5. If there is no voltage drop across the part, but one lead of the part connects to an operating circuit, both ends of the part will be at the same potential with respect to all other points in the circuit.

Instructions for Statement No. 16: If the resistance of a part being checked is fairly large compared to the resistance of your tvom, you will not get the expected voltage measurements when you check the continuity of the part. We will prove this point in this statement experiment. We will substitute the 10-megohm resistor for R_4. To do this, solder one end of the 10-megohm resistor to terminal 15 (chassis). Leave the other end free. Clip the tvom ground clip to the free end of this resistor and touch the probe to terminal 7. A reading here indicates that
.34 continuity exists through the 10-megohm resistor. Now touch the probe to terminal
1.65 12. Jot down the approximate reading, and answer the Statement. Turn off S_1 and your tvom, unsolder the 10-megohm resistor but leave the batteries as well as R_1, R_2, and R_3 connected. Save the dummy resistor for later use.

Statement No. 16: When I measured the voltage between the free end of the 10-megohm resistor and terminal 12, I found that the meter pointer was closest to:

(1) zero
[✓ *(2) 1.5 volts*]
(3) 3 volts

on the 0-3 volt dc scale.



$\frac{3}{18 \text{ meg}}$

.17 μA

EXPERIMENT 17

Purpose: To show that the sum of the currents flowing away from a point is equal to the current flowing to that point.

Introductory Discussion: In this experiment we will construct the series-parallel circuit shown in Fig. 17-1. Current I_1 flows through the branch consisting of R_1 and R_4, and current I_2 flows through the branch consisting of R_2 and R_3. Both of these currents, which together make up the total current drawn from the battery, flow through resistor R.

Since R, R_1, and R_2 are 1K-ohm resistors, we can measure the three currents in terms of milliamperes. As you have learned, the voltage drop in volts across a 1K-ohm resistor is equal to the current in milliamperes flowing through it.

The accuracy of the measurements will depend on the tolerances of the three resistors. If each is exactly 1K ohm, then the current measured for I will exactly equal I_1 plus I_2. However, since the resistors have a tolerance of plus or minus 10 percent and therefore may not be exactly 1K ohm each, the readings may be off a little.

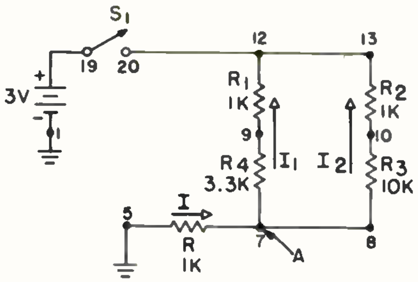


Fig. 17-1. Circuit for Experiment 17.

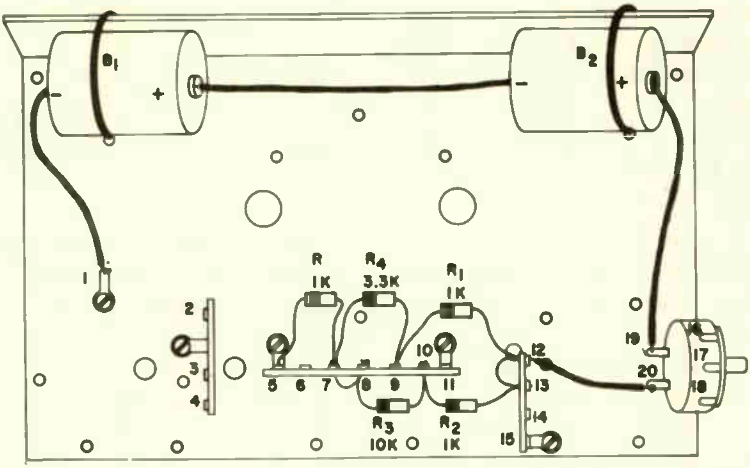


Fig. 17-2. Chassis arrangement for Experiment 17.

Experimental Procedure: For this experiment, you will need your tvom, the chassis with parts installed, and the following parts:

1 1K-ohm resistor
Hookup wire

Fig. 17-2 shows the parts arrangement needed to perform this experiment. To construct this circuit, unsolder the 10K-ohm resistor lead from terminal 5 and resolder it to terminal 10. Then install the 1K-ohm resistor from terminal 10 to terminal 13.

Finally, connect terminals 7 and 8 with a 2″ length of hookup wire, and connect terminals 12 and 13 with another 2″ length of hookup wire. These jumpers are purposely made longer than necessary so that the circuit can be changed easily later. Turn on S_1 and your tvom and proceed with Step 1.

Step 1: To measure current I through resistor R.

Clip the ground lead of your meter to the chassis and touch the probe to terminal 7. Record your reading on the 3-volt scale in Fig. 17-3 as the current I in milliamperes. As you can see from examining the schematic in Fig. 17-1, all the electrons making up the current drawn from the battery flow through resistor R.

Step 2: To measure current I_1.

Current I_1 flows through resistors R_1 and R_4. Since this is a series circuit, the

CURRENT MEASURED	YOUR READING
CURRENT I THROUGH R	.75 ma
CURRENT I_1 THROUGH R_1	.52 ma
CURRENT I_2 THROUGH R_2	.22 ma.
CURRENT $I_1 + I_2$	.74 ma

Fig. 17-3. Record your readings for Experiment 17 here.

same current flows through both resistors. By measuring the voltage drop across R_1 we can interpret this as current I_1 in milliamperes through both resistors. To make the measurement, clip the ground lead of the tvom to terminal 9, the junction of R_1 and R_4, and touch the probe to the end of R_1 going to terminal 12, the positive battery terminal. Record your reading in Fig. 17-3 as the current I_1 in milliamperes.

Step 3: To measure current I_2.

Since R_2 and R_3 are in series, the same current flows through each. Measuring the voltage drop across the 1K-ohm resistor R_2 gives us the current in milliamperes. To make the measurement, clip the ground lead of the tvom to terminal 10, the junction of R_2 and R_3, and touch the probe to terminal 12 or 13, the end of R_2 going to the positive battery terminal. Record in Fig. 17-3 the voltage across R_2 as the current I_2 in milliamperes. Turn off S_1.

Step 4: To find the sum of I_1 and I_2.

Add the values you obtained for I_1 and I_2 and record their sum in the space provided in Fig. 17-3.

Discussion: Compare the current you measured for I with the sum of the currents you measured for I_1 and I_2. They should be approximately equal. However, you must remember that because of parts tolerances, the measured values may not be exactly equal. If these values are equal, it means that the three 1K-ohm resistors that you have are exactly equal and that the measurements in each case happen to fall on a marked scale division so that you could read them exactly. This is extremely unlikely, although possible. If the difference between the sum of I_1 and I_2 and current I is not greater than ±20%, your results are good.

The current flowing to point A in Fig. 17-1 is the current I. The current flowing away from point A is the sum of I_1 and I_2. You should have found that this sum was approximately equal to I. In other words, the current flow to point A is equal to the current flowing away from it. This is an important law known as Kirchhoff's Current Law. You will see applications of it time and time again in your electronics career.

Instructions for Statement No. 17: For the Statement we will change the circuit in Fig. 17-1 by placing resistor R between the positive battery terminal and the junction of R_1 and R_2. The new circuit will be like Fig. 17-4. With the circuit changed, we will see if the currents flowing to point B add up to the current flowing away from this point.

By simply reconnecting the two jumpers used in Fig. 17-2, we can change the circuit to that of Fig. 17-4. Resistors R and R_1 become interchanged. That is, resistor R in Fig. 17-4 was R_1 in Fig. 17-2 and resistor R_1 in Fig. 17-4 was R in Fig.

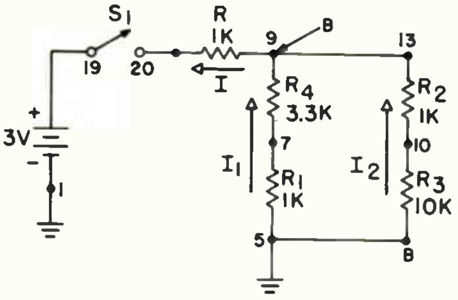


Fig. 17-4. Circuit for Statement 17.

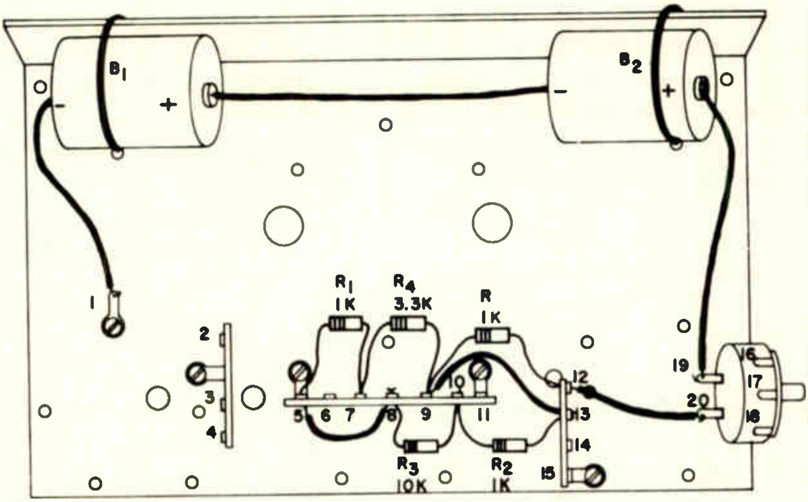


Fig. 17-5. Parts arrangement of Fig. 17-4.

17-2. Both resistors are 1K-ohm, so all is well.

To change the circuit, unsolder the jumper wire going to terminal 7 and resolder it to terminal 5. Unsolder the jumper lead going to terminal 12 and resolder it to terminal 9 as shown in Fig. 17-5. With the circuit changed, we will see if the currents flowing to point B add up to the current flowing away from this point.

Turn on S_1 and measure the current through R by connecting the meter clip to terminal 9 and the probe to terminal 12. Record your reading for I in Fig. 17-6. Now measure the current through R_1 by connecting the meter ground clip to the chassis and touching the probe to terminal 7. Record this reading as I_1 in Fig. 17-6. Finally, measure I_2 by connecting the meter ground clip to terminal 10 and the probe to terminal 13. Record your reading in Fig. 17-6. Add up the currents I_1 and I_2 and enter the sum in Fig. 17-6. Now you can answer the statement.

Turn S_1 off and unsolder and remove the resistors and jumper wires. Leave the battery connected to terminals 1 and 19.

Statement No. 17: **I found that the sum of I_1 and I_2 was:**

[✓ *(1) approximately equal to*]
(2) considerably greater than
(3) considerably less than

current I.

CURRENT MEASURED	YOUR READING
CURRENT I THROUGH R	.~~3~~725
CURRENT I_1 THROUGH R_1	.54
CURRENT I_2 THROUGH R_2	.22
CURRENT I_1+I_2	.76

Fig. 17-6. Record the readings for Statement No. 17 here.

Putting Your Ohmmeter Into Operation

The ohmmeter section of your tvom should be ready to operate. You assembled it and installed the battery when you constructed the unit. If your tvom has been operating properly up to this point, you should have no difficulty with the ohmmeter.

TRYING OUT THE OHMMETER

Turn on the tvom and set the function switch to dc, and the range switch to R X 1. Carefully adjust the zero set knob on the front panel. Look to see that the test leads from the meter are not touching, and rotate the function switch to the "ohms" position. The meter pointer should move upscale. If it moves downscale, you have the flashlight cell installed backwards.

Bring the meter pointer over the last mark on the right on the ohmmeter scale (the red scale on the meter) by adjusting the front panel ohms set knob.

If you cannot get it to the last mark, the flashlight cell voltage is too low, and you should install another cell. You should check the calibration adjustment of the voltmeter when the flashlight cell is replaced.

Turn the range knob through its various positions. The meter pointer should remain in approximately the same position for any position of the range switch. If there is much variation, the meter reading can be brought back to the last mark on the ohmmeter scale by means of the ohms set knob.

Turn the range switch to the R X 1 position and clip the ground lead to the probe tip. The meter will indicate a fraction of an ohm. This reading is normal and is due to the small resistance in the ground lead and the probe cable.

Turn the range switch to the R X 1M position. The meter pointer will swing to the left, coming to a stop approximately at zero on the ohms scale. This indicates there is zero resistance between the clip and the probe. The fraction of an ohm of resistance in the ground lead and cable is not indicated with high range switch settings. When you separate the clip and the probe, the meter pointer will swing all the way to the right to the last mark on the ohmmeter scale.

It is important that you know the meaning of these two marks. The one at the right means that the resistance between the test leads is too high to be read, and the zero mark at the left means that the resistance between the two probes is too low to be read.

Let us see how the ohmmeter works.

HOW YOUR OHMMETER WORKS

An ohmmeter does not measure the resistance of a part directly. It measures either the current flowing through the part or the voltage drop across the part. Your Model 212 and most commercial tvom's use the latter method.

As you already know from the discussion in Experiment 11, the bridge circuit in your tvom when balanced gives a zero reading on the meter scale. When a voltage is applied to the bridge, unbalancing it, there is a reading which depends upon the amount of the voltage.

A schematic diagram of your ohm-

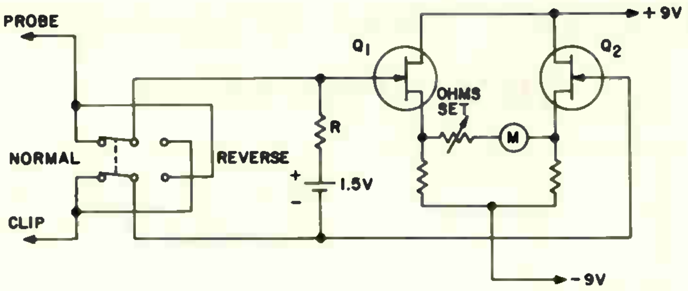


Fig. 14. Ohms circuit of TVOM.

meter circuit is shown in Fig. 14. When the ohmmeter is in use, the additional parts consist of the 1.5-volt cell, a resistor, and the ohms set rheostat in series with the meter. When the probes are separated, there is no voltage drop across the resistor, and the 1.5 volts is applied directly to the bridge circuit. When the ohmmeter is to be used, the ohms set is adjusted so the meter pointer moves all the way to the right. When the test probes are held together, no voltage is applied to the bridge circuit, and the meter pointer goes all the way to the left on the ohms scale.

If a resistor is connected between the ground clip and the probe, the 1.5-volt source voltage divides between the resistor built into the tvom and the external resistance under test. The voltage drop across the resistor being tested is applied to the bridge circuit. The meter is calibrated to give readings in ohms, corresponding to these voltage drops. Thus, the meter is actually measuring the voltage drop, but the scale is marked in ohms to give a direct resistance reading.

For each ohmmeter range position a definite resistor value is switched into the circuit. On the R X 1 range, we have a 10-ohm resistor; on the R X 10, a 100-ohm resistor; on the R X 100, a 1K-ohm resistor; on the R X 1K, a 10K-ohm resistor; on the R X 10K, a 100K-ohm resistor; on the R X 100K, a 1-meg resistor; and on the R X 1M, a 10-meg resistor. Since all of these ranges are multiples of 10, we can use the same ohmmeter scale for each range. On R X 1, the scale can be read directly. On the R X 10 range, we multiply the scale reading by 10. On the R X 100 range, we multiply the scale reading by 100. On the R X 1K range, we multiply the scale reading by 1000. On the R X 10K range, we multiply the scale reading by 10,000. On the R X 100K range, we multiply the scale reading by 100,000, and on the R X 1M range, we multiply the reading by 1,000,000. On this range we simply read the scale directly in terms of megohms (million ohms) rather than ohms.

The scale is arranged so that 10 falls in the center of the scale. If we measure a 10-ohm resistor on the R X 1 range, the resistance in the tvom and the external resistance will be equal, and the meter will read half-scale. The cell voltage divides equally between the resistance in the tvom and the external resistance. The meter will read half-scale on each range when the resistor under test equals the internal resistance of the ohmmeter. If a resistance higher than the internal resistance is measured, more of the voltage will be dropped across it and applied to the bridge circuit, and a higher value will be indicated. If a resistor lower than the one in the ohmmeter being tested, less of the voltage will be dropped across it, and a smaller voltage will be applied to the bridge circuit, giving a smaller deflection and a lower resistance reading.

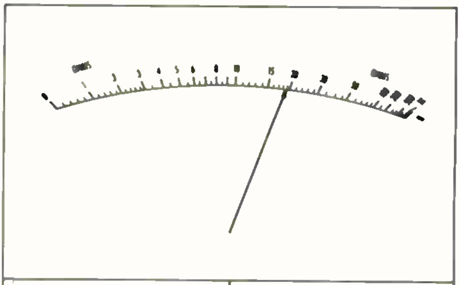
The values that can be read on any range are the ones included between the first mark on the ohmmeter scale to the right of zero and the 1K mark.

Thus, on the R X 1 scale, we can read values from .2 ohm to 1000 ohms. On the R X 10 scale, we can read values from 2 ohms to 10,000 ohms. On the R X 100 scale, we can read values from 20 ohms to 100K ohms. On the R X 1K range, we can read values between 200 ohms and 1 megohm. On the R X 10K range, we can read values between 2000 ohms and 10 megohms. On the R X 100K range, we can read values between 20,000 ohms and 100 megohms. On the R X 1M range, we can read values between 200,000 ohms and 1000 megohms.

These are the maximum extremes that can be measured on the various ranges. Actually, a range should be used that will give a deflection as near the center of the scale as possible. Avoid using a range that gives a reading on the extreme right.

READING THE METER SCALE

An expanded view of the meter scale is shown in Fig. 15 with the values of the in-between markings clearly illustrated. Study this and the scale on your meter until you are able to identify the values of the unmarked divisions quickly.



RANGE SETTING	VALUE INDICATED
R X I	19
RX10	190
RX100	1,900
R X IK	19,000
R X 10K	190,000
R X 100K	1,900,000
R X IM	19 MEG

Fig. 16. When the meter points to the first line before 20 on the ohms scale, the value indicated depends on the setting of the range switch.

For practice assume that the meter pointer rests at a certain position and then figure out what value this position would indicate on the various ranges.

Assume that the meter pointer points to the division just before 20. Write down the value this would indicate for each range of the ohmmeter. Then compare your reading to the ones in Fig. 16.

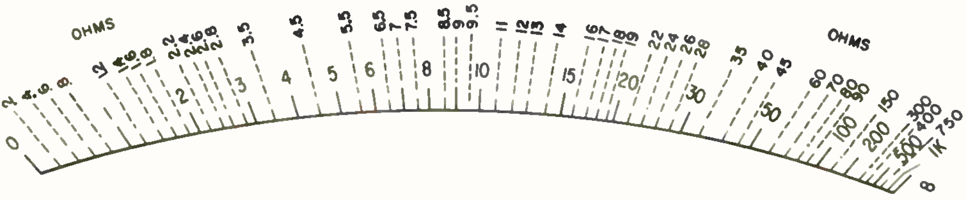


Fig. 15. An expanded view of the ohmmeter scale of the tvom.

Remember that the R X 1 scale is read directly in ohms, and the R X 1M scale is read directly in megohms.

Although, as we have said, your ohmmeter works by voltage division, you must remember that some current is drawn from the cell. With the range switch in the R X 1 position and the test leads shorted together, you have a 10-ohm resistor connected directly across the cell and considerable current is drawn from the cell. Do not leave the probes together for any length of time on the two lowest ohmmeter ranges. Make the readings quickly so you can disconnect the test probes and prolong the life of your flashlight cell. However, since replacement cells are inexpensive and are easy to install, you should take enough time to get satisfactory readings.

EXPERIMENT 18

Purpose: To show how practical measurements on individual resistors are made with an ohmmeter; and to show the precautions necessary for satisfactory results.

Introductory Discussion: In checking parts with an ohmmeter there are three important rules to bear in mind. These are:

1. Make sure the equipment in which the part under test is used is turned off. If it is supplied from the power line, turning the equipment power switch to the off position is usually sufficient. Many technicians, however, make it a rule to remove the power line plug of the equipment from the wall socket. Then there is no question that the power has been disconnected, and there is no chance of turning the switch on while checking the volume control, which may be part of the switch.

If the equipment is battery operated, all the batteries should be disconnected, because the on-off switch might disconnect only one battery terminal, leaving the other terminal connected to the circuits. In making tests with your ohmmeter, you might complete the battery circuit through your meter. If there is voltage across the part being tested, the resistance measurement is meaningless and if the voltage is high, the ohmmeter might be damaged. We will show what happens when voltage is present across a resistor being checked with an ohmmeter.

2. Use the correct range of the ohmmeter. As you will demonstrate, if you use the wrong range, the ohmmeter may indicate a good part is open or shorted.

3. Keep your fingers off the parts under test when measuring high resistances. The resistance of your body can affect the results of your measurements. On low resistances it does not matter. Do not touch the probes when checking iron-core devices, such as transformers or chokes, or you may receive a serious shock.

As you continue working with your ohmmeter, you will learn other valuable tricks of the trade that will enable you to get the greatest use from the ohmmeter section of your tvom.

Experimental Procedure: In this experiment you will need your tvom, the 3-volt battery, and the following parts:

1 10-megohm resistor
1 1-megohm resistor

1 100K-ohm resistor
1 22K-ohm resistor
1 18K-ohm resistor
1 10K-ohm resistor
1 3.3K-ohm resistor
3 1K-ohm resistors
1 Alligator clip

Turn the tvom on and turn the function switch to the dc position. Carefully adjust the zero set control. Now turn the function switch to the ohms position, and the range switch to the R X 1M position. Adjust the ohms set control so that the meter pointer is over the last division at the right on the ohms scale. Now hold the test leads together; the pointer should move to zero on the left of the scale. You are now ready to demonstrate the first step in the experiment. Slip the alligator clip over the tvom probe as you did in Experiment 14. This will make it easier to connect the ohmmeter to the circuits used in this experiment.

Step 1: To show the effect of touching the circuit under test when measuring large resistance values.

In this step you will first use the 10-meg resistor. With the resistor on your workbench, clip the ground lead of the tvom to one lead of the resistor and the probe to the other resistor lead. You will get a reading of approximately 10 megohms. Let us see how we read this. The meter pointer should point to about 10 on the ohms scale and this, of course, means 10 megohms on this range.

Now with the ground lead and the probe clipped to the 10-megohm resistor, grasp one test clip in each hand. This places your body in parallel with the 10-megohm resistor. Note the change in the meter reading. The large reduction in the reading shows that your body resistance is in parallel with that of the 10-megohm resistor. You might measure 2 megohms, 4 megohms, or 6 megohms, depending upon the moisture on the surface of your skin and the pressure you exert in touching the test leads. In any event, you can see that such a test of the resistor gives meaningless results.

Lay the 10-megohm resistor to one side, and set the range switch to the R X 10K position. Connect the ground clip to one lead of the 100K-ohm resistor, and the probe to the other end, and note the reading. Grasp one test clip in each hand, placing yourself across the resistor. Again note that there is a reduction in the resistance reading, although considerably less than in the case of the 10-megohm resistor. The reduction is less because the resistance of your body across the 100K-ohm resistor causes less of a change in the resistance between the ohmmeter leads.

Now disconnect the 100K-ohm resistor and lay it to one side. Place the range switch in the R X 1K position. Connect the ground clip to one lead of a 10K-ohm resistor, and the probe to the other end. Your reading will be somewhere near 10 on the ohms scale. Multiplying this by 1000 will give you the approximate value of the resistor. Now touch the ground clip with the fingers of one hand, and touch the probe with your other hand. Note that there is only a slight change in the resistance value.

This step showed you that touching the ohmmeter leads with your hands is not very important when measuring low resistances, but is extremely important when measuring high resistances. You should make it a habit to keep your hands off the circuit under test.

Step 2: To show that using the incorrect ohmmeter range may give misleading results.

Connect the ground clip to one lead of the 100K-ohm resistor, set the range switch to the R X 1 position, and touch the probe of the tvom to the free lead of the resistor. Note that there is no appreciable movement of the meter pointer, indicating, as far as this range is concerned, that the resistor is open. Now, remove the probe from the resistor, and switch the range switch to the R X 1M position. Again touch the probe against the free lead of the resistor. The pointer will move almost to zero, and you might conclude that the resistor was either completely or partially shorted. Now, remove the probe from the 100K-ohm resistor, and change the range switch to the R X 10K position. Touch the probe to the resistor again and you will find that the meter pointer swings to 10. Multiplying this by 10,000 gives us 100,000 for the value of the resistor.

From this demonstration you can see how important the choice of range is. Let us learn how to choose the right range.

Step 3: To show how to choose a suitable ohmmeter range.

A suitable ohmmeter range is one that is easily read. Before demonstrating this statement, examine Fig. 18-1. This chart lists the resistance values covered by each range. It also shows how many places to move the decimal point for each multiplying factor. For example, if the meter reads 10 when using the R X 10 range, move the decimal one place to the right, which gives you 100, the value of the resistor under test.

RANGE	COVERAGE	NO. OF PLACES TO RIGHT TO MOVE DECIMAL POINT
R X 1	.2 OHM TO 1K OHMS	0
R X 10	2 OHMS TO 10K OHMS	1
R X 100	20 OHMS TO 100K OHMS	2
R X 1K	200 OHMS TO 1 MEGOHM	3
R X 10K	2K OHMS TO 10 MEGOHMS	4
R X 100K	20K OHMS TO 100 MEGOHMS	5
R X 1M	200K OHMS TO 1000 MEGOHMS	6

Fig. 18-1. The resistance values covered by each range of the ohmmeter.

To find the ohmic value when the meter reads 30 using the R X 100K range, move the decimal point five places to the right, which gives 3,000,000 or 3 megohms.

When the readings fall on unmarked values to the left of 6, the meter value will end with a decimal. Thus the line between 5 and 6 is 5.5. On the R X 10 range, a meter reading of 5.5 is 55 ohms. Also notice that the long mark between 6 and 8 is not numbered and it represents 7. Likewise, the long mark between 8 and 10 is not numbered and it represents 9. The short marks between 6 and 7, 7 and 8 and 8 and 9 indicate a value ending in .5.

Suppose you are using the R X 10K range, and the meter pointer is on the third mark past zero. This is .6. To get the reading in ohms, multiply .6 by 10,000 or move the decimal point four places to the right. The answer is 6000 ohms.

With practice you will be able to read

values quickly and easily. Many times you can tell the range to use by reading what the value is supposed to be on the schematic diagram.

Let us see which range to use for your 18K-ohm resistor. First, put the range switch in the R X 1 position. Clip the ground lead to one lead of the resistor, and the probe to the other lead. Record your reading in Fig. 18-2. Now, move the range switch to each of the other positions, and watch the meter. Record your meter readings in the spaces marked "Reading" in Fig. 18-2. Figure out the value in ohms by multiplying each reading by the multiplying factor for each range setting. Write these under "Value" for each range.

When you use the R X 1 range, the pointer will be all the way over to the right, so you know the resistance is more than 1000 ohms, so you switch to the next range. On R X 10, the pointer still stays all the way over to the right, so again you switch to a higher range. On R X 100, the pointer should be between 150 and 200, so switch to a higher range. On R X 1K, the pointer should be at about 18; on R X 10K, it will be anywhere from 1.6 to 2; on R X 100K, it will move past the first scale division on the left, .2; and on the R X 1M range, there will be no perceptible reading.

From these, you know that the resistance you are measuring will be more than 1000 ohms, and less than 20,000 ohms. You could read it on the R X 100, the R X 1K or the R X 10K range. You will get a more accurate reading on the R X 1K range, because at that part of the scale, each division represents 1, and the reading is near the center of the scale. On the R X 100 range the reading is way over to the right, and each division represents 50 or 100. On the R X 10K range the reading is way over to the left, and each division represents 2.

The readings you obtain might be closer together or even farther apart than those shown in Fig. 18-2. Exact agreement is very unusual and, as you will learn, unnecessary. Since the readings are taken on different parts of the scale, the error introduced by the meter itself and by the resistors in the instrument may vary. For service and general electronic work such an error is unimportant.

Now check each of your resistors on

RANGE	R X 1		R X 10		R X 100		R X 1K		R X 10K		R X 100K	
	READING	VALUE	READING	VALUE	READING	VALUE	READING	VALUE	READING	VALUE	READING	VALUE
SAMPLE FIGURES	1K +	1K +	1K +	10K +	150 +	15K +	18	18 K	1.6 +	16 K +	LESS THAN .2	LESS THAN 20K
YOUR FIGURES	1K+	1K+	1K+	10K+	200+	20K+	16	16K	1.7	17K	.2 -	20K

Fig. 18-2. Record your reading for each range setting under the column headed "Reading". Record the value that reading indicates on each range under the heading "Value".

each range, recording your scale readings in Fig. 18-3, and the value this reading indicates. Clip the ground lead to either lead of the resistor being measured, and the probe to the other lead. Turn the range switch to the positions indicated on the top of the table, and enter the meter reading you obtain under the heading marked "Reading." Compute the ohmic value of the resistor, and enter it in the space marked "Value."

For the 1K-ohm reading, use any one of the 1K-ohm resistors. For the 330-ohm resistance you are to measure, connect the three 1K-ohm resistors in parallel. To do this, clip the tvom ground lead to one end of all three 1K-ohm resistors, and the probe to the other ends.

Practice working out the ohmic value of each reading you record in Fig. 18-3. If you find one range is as easy to read as another, it does not matter which range you use.

If you want the greatest accuracy, use the range that gives an indication nearest the center of the scale. For example, when you measure the 330-ohm resistance on the R X 1 range, the pointer will move between 200 and 300 at the right-hand side of the scale, but that is about as close as you can read it. On the R X 1K range, it will move between .2 and .4, so you know the value is between 200 and 400. However, on the R X 100 range, it will move to the first division past 3, so you know the value is between 300 and 350. This is the best scale to use for this particular resistance value.

Step 4: To show that power must not be applied to a circuit when ohmmeter tests are made.

Connect a 1K-ohm resistor, a 10K-ohm resistor and a 22K-ohm resistor in series. Connect the free lead of the 1K-ohm resistor to terminal 15 and connect the 22K-ohm resistor to terminal 20, as shown in Fig. 18-4. Make sure S_1 is off. To make the connections to the 10K-ohm resistor, simply twist the resistor leads together for this temporary connection. Note that the circuit is not completed,

RESIS.	R X 1		R X 10		R X 100		R X 1K		R X 10K		R X 100K		R X 1 MEG	
	READING	VALUE	READING	VALUE	READING	VALUE	READING	VALUE	READING	VALUE	READING	VALUE	READING	VALUE
10 MEG	>1K	>1K	>1K	>10K	>1K	>100K	>1K	>1000 K	>1K	>10M	100	10M	9.7	9.7M
1 MEG	>1K	>1K	>1K	>10K	>1K	>100K	>1K	>1M	100	1M	10	1M	1.5	1.[illegible]M
100K	>1K	>1K	>1K	>10K	1K	100K	100	100K	9.5	95K	1	100K	.1	100K
22K	>1K	>1K	>1K	>10K	300	30K	22	22K	2.4	24K	.15	15K	0	0M
10K														
3.3K														
1K														
330														

Fig. 18-3. Record the reading and the indicated value on each range for each of the resistances listed.

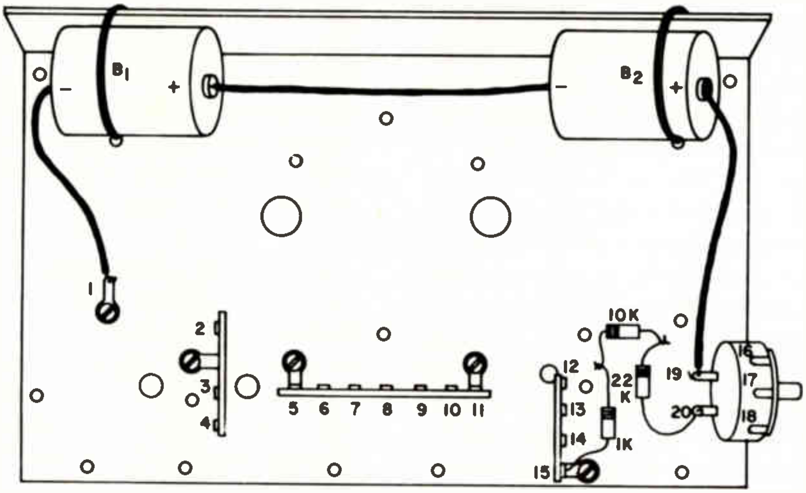


Fig. 18-4. Circuit for Step 4.

since S_1 is off and the 22K-ohm resistor is not connected to the positive terminal of the battery. Consequently, there will be no voltage drops across the resistors, and no current flow through the circuit.

Measure the resistance of the 1K-ohm resistor by clipping the ground lead to the chassis. Set the range switch of the tvom to the R X 1K position, and clip the probe to the junction of the 1K-ohm and 10K-ohm resistors. The meter needle will indicate approximately 1; multiplying this by 1000, you get 1000 ohms for the resistance of the resistor.

Clip the probe to the junction of the two resistors and turn on S_1. Note that there is a marked increase in the resistance reading, so much so, in fact, that you might suspect that the resistor was defective. Turn off S_1 but do not dismantle the circuit. You will use it again to answer the statement.

Discussion: In this experiment you have learned that you must choose a suitable ohmmeter range. The wrong range might indicate that a good resistor is open or that it is shorted. Also, you must choose a suitable range so that the value can be read easily and accurately.

You have seen that if power is applied to a circuit in which a resistance measurement is being made, the measurement will be so far off as to be meaningless.

You have found that the ohmmeter is not 100% accurate. However, in service work, this is unimportant. When making resistance measurements on equipment you have been called upon to repair, you are looking for an open, for a short, or for a radical change in resistance value. If a part has changed sufficiently in resistance so that the equipment operates improperly, the change will be large. You would not expect a change of 25% to cause trouble in most circuits. In general, the change, if that is what the trouble is, will be 50% or more. For example, you might find that the plate load resistor of an amplifier had changed from its normal value of 100,000 ohms to 20,000 ohms. This would cause a marked loss in gain, and cause excessively high plate voltage.

When a technician has improperly operating equipment, he does not check the value of each and every resistor with his ohmmeter. He localizes the trouble to a section and then to a stage. Then he decides whether to make ohmmeter measurements or other measurements according to the symptoms he discovers. You will be taught how to localize trouble to a stage, and from the symptoms, to decide what type of test should be made.

There are, of course, many uses for an ohmmeter besides just checking individual resistor values. We will describe other uses in later experiments.

Instructions for Statement No. 18: In Step 4, you saw that if voltage was applied to the resistor under test, the reading was incorrect. We are now going to see if the polarity of this voltage has any effect on the reading by reversing the ohmmeter connections.

Make sure the tvom polarity switch is set to normal. Connect the ground clip of your tvom to the junction of the 10K-ohm and 1K-ohm resistors. Set the range switch to R X 1K, and touch the probe to the chassis. You are again measuring the 1K-ohm resistor. While holding the probe against the chassis, turn on S_1. Note the new ohmmeter reading. You now have sufficient information to answer the statement. Take the circuit apart, but leave the batteries connected and in place on the chassis.

Statement No. 18: When I turned on S_1, the ohmmeter reading:

(1) increased.
[✓ *(2) decreased.*]
(3) remained unchanged.

EXPERIMENT 19

Purpose: To show how circuit continuity can be checked with an ohmmeter, and to show that the presence of continuity does not indicate the condition of all parts in the circuit.

Introductory Discussion: You have seen how circuit continuity can be checked with a voltmeter and that continuity indicates only that the circuit will carry current. Parts may be shorted or may have changed in value without affecting the ability of the circuit to carry current. If a circuit has continuity, it simply means that the circuit is not open.

Most technicians prefer the ohmmeter for continuity testing, since it can easily be shifted to various points in the circuit to measure their actual resistance. When making continuity tests, the ohmmeter is not used to measure the total resistance of the circuit, although it does show the approximate sum of the resistances. The true purpose is to show that the circuit is complete. In making continuity measurements, technicians seldom bother to determine the resistance of the circuit. They simply check to see if there is a reading showing continuity.

In this experiment, you will demonstrate that in a circuit containing large and small resistances, a small resistor could be shorted without materially affecting the resistance measurement. To find such a short, a check of the individual resistors would be required. This would be done only if the symptoms indicated that it was the cause of the difficulty.

Experimental Procedure: In this experiment, you will need your tvom, the dummy resistor you built in Experiment 16 and the following parts:

- 1 10-megohm resistor
- 1 1-megohm resistor
- 1 100K-ohm resistor
- 1 22K-ohm resistor
- 1 10K-ohm resistor
- 1 1K-ohm resistor

In this experiment, you will make up a voltage divider using five resistors in series, and check the continuity. You will not use the chassis for this experiment, simply solder the 10-megohm, the 1-megohm, the 100K-ohm, the 1K-ohm, and the 10K-ohm resistors together as shown in Fig. 19-1. You are now ready to conduct the first step in this experiment.

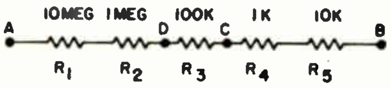


Fig. 19-1. Voltage divider you will use in Experiment 19.

Step 1: To determine accurately the resistance between terminals A and B of the voltage divider.

STEP	MEASUREMENT	VALUE
1	R_1	9.6 Meg
	R_2	1. Meg
	R_3	.96 K
	R_4	.900K
	R_5	8.8K
	TOTAL	10.7057 Meg
2	A TO B	11 Meg
3	R_4 AND R_5 SHORTED	11 Meg
4	R_4 = 22K	

Fig. 19-2. Record your readings for Experiment 19 here.

9.6 Meg
1.
.096
.0009
.0088
10.7053

Measure the value of each resistor in the divider, and record the resistance in ohms in the spaces provided in Fig. 19-2 for Step 1. Now add up the values of all five resistors and record this as the total resistance in the space provided.

Step 2: To measure the resistance between terminals A and B of the voltage divider.

Connect the ground clip to the end of the divider marked A in Fig. 19-1. Touch the probe to the end of the divider marked B, adjust the range switch to give a reasonable indication, and record the value in Fig. 19-2. Your reading should be approximately the same as the sum of your individual resistance measurements.

Step 3: To show the effect on the total resistance of shorting a relatively small resistance.

To simulate a short across resistors R_4 and R_5, solder a short piece of wire from point C to point B. Connect the ground clip to point A, and the probe to point B. Record your reading in the space provided in Fig. 19-2. The value should be almost the same as that obtained in Step 2, showing that the two resistors could be completely shorted without materially affecting the ohmmeter measurements.

Step 4: To show that an increase in a relatively small resistor in a circuit will have no noticeable effect on the total resistance of the circuit.

Remove the 1K-ohm resistor, R_4, from the circuit, and replace it with the 22K-ohm resistor. A change in resistance value from 1000 ohms to 22,000 ohms is perfectly apparent, if you check the individual resistors. Let us see how it affects the total resistance. Check the resistance from A to B, and record your result in Fig. 19-2.

Step 5: To show how lack of continuity is indicated in a resistance circuit.

Remove the 22K-ohm resistor, and in its place substitute the dummy resistor you made in an earlier experiment, between R_3 and R_5. Now measure the resistance between A and B. You will find that the circuit is either open, indicated by no movement of the meter needle from the open position at the extreme right, or that the resistance is extremely high. You might read a value such as 1K, which would mean 1000 megohms. This would be through the resistance of the insulation around the wires of the dummy resistor where they are wrapped together. A value of 1000 megohms, however, would be interpreted as an open in a circuit with an original total resistance of approximately 11 megohms.

Step 6: To find the open part in a circuit having no continuity.

To find the open in the voltage divider consisting of R_1, R_2, R_3, the dummy resistor, and R_5, connect the ground clip to point A. Now touch the probe to point B. Notice that there is no continuity. Move the probe to the junction of the dummy resistor and R_5. Again note that there is no continuity reading. Move the probe to point C, the junction of R_3 and R_4. Here there is continuity, showing that in making your measurements, you just passed over the defective part. You can check the part by connecting the ohmmeter test probes directly across it, proving that there is an open.

Discussion: In this experiment, you have seen that continuity can be checked with an ohmmeter. If the battery in the ohmmeter can force even an extremely small amount of current through the circuit, there will be an indication on the proper ohmmeter range. If there is no continuity, the meter needle will not move at all or will move only slightly, giving an extremely high resistance reading. By examining the diagram of the circuit whose continuity you wish to measure, you can, by adding the values of the resistors as marked on the diagram, determine what the approximate total resistance will be. This will show you what to expect and help you to choose an appropriate resistance range if you want to check the resistance. However, if you simply wish to check for continuity, you can use any range that gives a reasonable meter pointer movement.

You have seen that we can reduce the resistance of the divider in Fig. 19-1 by completely shorting out R_4 and R_5 without changing the measured total resistance.

Because of this fact, it is apparent that to check this condition of individual resistors in a circuit having a high resistance, you must connect the ohmmeter directly across each resistor in question. You have also seen that a radical increase in resistance of one of the low resistance parts will have no apparent effect on the total measured resistance. These are points to remember when troubleshooting electronic equipment. You make continu-measurements when you suspect a circuit is open. This does not show the value of the individual parts.

Instructions for Statement No. 19: In working with the voltage divider shown in Fig. 19-1, you saw that there was no change in the total resistance when resistors R_4 and R_5 were shorted. These, however, have a relatively low value. Now we will see what happens when R_3, R_4, and R_5 are shorted. First, remove the dummy resistor from the circuit, and reconnect the 1K-ohm resistor so that the circuit again is like that shown in Fig. 19-1. Recheck the resistance between A and B, and jot down your reading. Then, solder a piece of wire between point D and point B on the divider to simulate a short across R_3, R_4, and R_5. Again measure the resistance from A to B and note the reading. You now have sufficient information to answer the statement. Unsolder the resistors.

Statement No. 19: When measuring the divider resistance with R_3, R_4, and R_5 shorted, I found that this value was:

[✓ *(1) the same as*]
(2) noticeably more than
[✓ *(3) noticeably less than*]

the value measured between A and B with all of the resistors in the circuit.

EXPERIMENT 20

Purpose: To show how to find the combined resistance of resistors connected in parallel; and to show that the resistance of one cannot be measured without being disconnected from the others.

Introductory Discussion: You already know that parts connected in parallel have a combined resistance less than that of the smallest resistor in the group. However, the serviceman may want to know what the exact combined resistance should be so he can measure the combined resistance and decide if the parts are in good condition.

In Experiment 18, you connected three 1K-ohm resistors in parallel to get a resistance of approximately 330 ohms. When the parallel-connected parts have the same resistance, it is easy to decide what the combined resistance should be. The rule is as follows: The combined resistance of equal parts in parallel is equal to the resistance of one of the resistors divided by the number of resistors in the group.

Thus, if we connect three 1K-ohm resistors in parallel, the combined resistance is 1000 divided by 3, or 333 ohms. Three 3.3K-ohm resistors in parallel have a resistance of 1000 ohms; two 22K-ohm resistors in parallel have a combined resistance of 11,000 ohms.

Parallel-connected resistors are not necessarily equal in value. The combined resistance, R, can be found by using the formula,

$$R = \frac{R_1 \times R_2}{R_1 + R_2}$$

For example, if we have a 1K-ohm resistor and a 3.3K-ohm resistor in parallel,

$$R = \frac{1000 \times 3300}{1000 + 3300}$$

$$= \frac{3{,}300{,}000}{4300}$$

$$= 769 \text{ ohms}$$

It is not important for you to be able to do these computations, because as a busy technician you won't waste time on them. Instead, if you cannot tell the combined resistance at a glance, you will unsolder one end of each one of the resistors and check the resistors individually. If you have the time to spare, and find the computations easy to do, then you do not need to go to the trouble of unsoldering a component to find out whether or not the combined resistance is correct.

When resistors do not have any shunting (parallel connected) parts, the resistance value is checked without unsoldering the leads, by connecting the test probes directly across the resistor.

In this experiment you will connect resistors in parallel and check their measured combined resistance against their computed resistance to prove that the computed value is correct and to note the variations to be expected between the computed and measured values.

Experimental Procedure: In this experiment you will need your tvom and the following parts:

1 1K-ohm resistor
1 3.3K-ohm resistor
1 10K-ohm resistor
2 22K-ohm resistors
1 100K-ohm resistor
1 10-megohm resistor

In connecting the parts in parallel, it is not necessary to use your soldering iron. Hold the two resistors so two of their leads cross as shown in Fig. 20-1. Clip the ground lead directly to the point where the leads cross each other. Bend the free leads together and clip the probe to them.

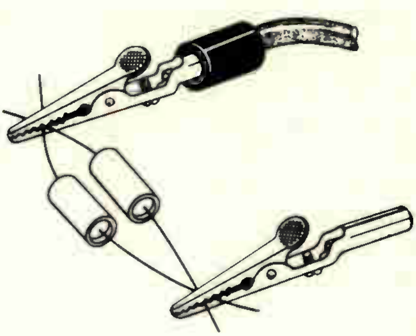


Fig. 20-1. How to measure two resistors in parallel.

You can then adjust the range selector switch for a reasonable reading.

Step 1: To find the combined resistance of a 1K-ohm and a 3.3K-ohm resistor in parallel.

As we have already shown, the computed resistance of a 1K-ohm and a 3.3K-ohm resistor in parallel is 769 ohms. To measure the combined resistance, connect the 1K-ohm and the 3.3K-ohm resistors in parallel. Clip one lead of your tvom to one end, and the other lead to the other end of the combination as shown in Fig. 20-1. Record the reading in the space in Fig. 20-2.

PARALLEL COMBINATION	COMPUTED VALUE	MEASURED VALUE
1K AND 3.3K	769 OHMS	
1K AND 10K	909 OHMS	780
10K AND 22K	6875 OHMS	6.9K
10MEG AND 100K	99K OHMS	97K
22K AND 22K	11K OHMS	11.5K

Fig. 20-2. Record your readings for Experiment 20 here.

Step 2: To find the combined resistance of a 1K-ohm and a 10K-ohm resistor in parallel.

Again we can compute the resistance of the combination from the formula:

$$R = \frac{R_1 \times R_2}{R_1 + R_2}$$

Substituting the values of the resistors, we have:

$$R = \frac{1000 \times 10{,}000}{1000 + 10{,}000} = 909 \text{ ohms}$$

Now let us measure the resistance of the combination. Clip the ground lead to one lead of each resistor, and the probe to the other end of each resistor. The correct way to do this is shown in Fig. 20-1. Record the reading in Fig. 20-2.

Step 3: To find the combined resistance of other parallel combinations of resistors.

Following the same procedure, measure the combined resistance of the other parallel combinations listed in Fig. 20-2. In each case, the computed value is given so that you can check your measured value with it.

Discussion: Now compare your measured values with the computed values given in the chart. They should be fairly close in most cases. However, because of the tolerances of the resistors, you may find that they differ quite a bit in some cases.

When two resistors are in parallel, and one is much larger than the other, the resistance of the larger cannot be checked unless it is disconnected. For example, when you measured the 10-megohm and the 100K-ohm resistors in parallel, their combined resistance should have been close to 100,000 ohms, the resistance of the smaller resistor. Even with the 10-megohm resistor completely removed, the resistance would still be close to the parallel value.

When there is only a slight difference in the values of the parallel resistors, if one is disconnected or is defective, there will be considerable change in measured value across the combination.

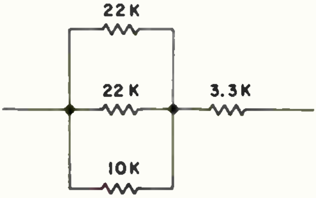


Fig. 20-3. Series-parallel circuit for Statement No. 20.

Instructions for Statement No. 20: To answer this statement, you are to build the series-parallel circuit shown in Fig. 20-3. You do not need to solder the resistor leads. Twisting them together is enough. Twist one end of a 10K-ohm resistor and two 22K-ohm resistors together. Twist the other ends and one end of a 3.3K-ohm resistor together as shown in Fig. 20-4.

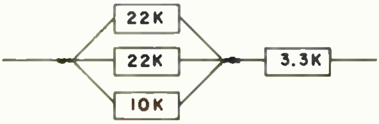


Fig. 20-4. How to arrange the parts for the circuit shown in Fig. 20-3.

Before you measure the combined resistance, examine the circuit carefully and see if you can decide in advance what the total resistance will be. As a matter of interest to yourself, jot down what you think it is on a separate sheet of paper. Now, connect the ground clip to one lead of the circuit and the probe to the other. Choose an appropriate range on your ohmmeter, and read the resistance value. Compare this with the value you chose by inspecting the circuit. You now have enough information to answer the statement. Separate the resistors.

Statement No. 20: When I measured the resistance of the circuit shown in Fig. 20-4, I found that the resistance was:

(1) *approximately 5500 ohms.*
[✓ (2)] *approximately 8500 ohms.*
(3) *approximately 13,000 ohms.*

LOOKING AHEAD

This completes the experiments in Kit 2T. When you have completed the second kit, remove the resistors and the potentiometer and clean the terminals. Leave the terminal strips, solder lugs, and battery connected. Make sure you have answered all the statements on the Report Sheet, fill in the top of the Report Sheet, and mail it to NRI for grading. While waiting for your graded answers to return, place your tvom in a safe place where it will not be damaged. Place all the left-over parts, listed in Table I, in a box and store them where they will not be lost. You can leave the two flashlight cells, the potentiometer and the terminal strips on the chassis plate. You may also leave the wires to the flashlight cells in place. Be sure to clean all excess solder from all of

1	Chassis plate
1	Alligator clip
1	Etched circuit board with tube socket
2	Large solder lugs
1	Marking crayon
2	4-40 hex nuts
1	1000-ohm potentiometer
1	470-ohm resistor
1	680-ohm resistor
3	1000-ohm resistors
1	3,300-ohm resistor
2	4700-ohm resistors
1	6,800-ohm resistor
2	10,000-ohm resistors
1	15,000-ohm resistor
1	18,000-ohm resistor
2	22,000-ohm resistors
1	82,000-ohm resistor
3	100,000-ohm resistors
1	220,000-ohm resistor
1	470,000-ohm resistor
1	1-megohm resistor
2	10-megohm resistors
2	1/4" X 4-40 machine screws
2	Silicon diodes
	Hookup wire
	Solder

Table I. Left-over parts to be stored for use later.

the terminals. The following parts are attached to the chassis plate:

2	Flashlight cells
1	3-lug terminal strip
1	4-lug terminal strip
1	7-lug terminal strip
1	Small solder lug
6	1/4" X 6-32 machine screws
6	6-32 hex nuts
1	Potentiometer mounting bracket
1	500K-ohm pot. with switch

While you are waiting to start on the next kit, clean the leads on the parts you have left over so you'll be ready to start your experiments when your graded answers are returned. Do not start the next kit until you have received a passing grade on the experiments in Kit 2.

In the next kit you will add parts to the circuit board of your tvom so you can measure ac. You will begin your study of ac circuits and see that many of the laws that you have verified for dc circuits can also be applied to ac circuits. You will also see how capacitors and coils act in ac circuits. Both audio signals and radio frequency signals are ac signals. Your next kit will be a big step forward for you. The experiments are designed to show how ac signals behave. The fundamentals you will study in Kit 3 will be used in later kits in your study of more complex circuits using vacuum tubes and transistors.

HEADING TOWARD SUCCESS

You have every reason to expect real success in your Electronics career. I base this statement on the following facts:

. . . you like Electronics and have much natural ability in this science.

. . . you are willing to work to increase your knowledge of Electronics, as proved by the progress you have made with your NRI course.

The above qualifications make for success, in the opinion of most experts. As Mark Sullivan once put it: "To find a career to which you are adapted by nature, and then to work hard at it, is about as near a formula for success and happiness as the world provides."

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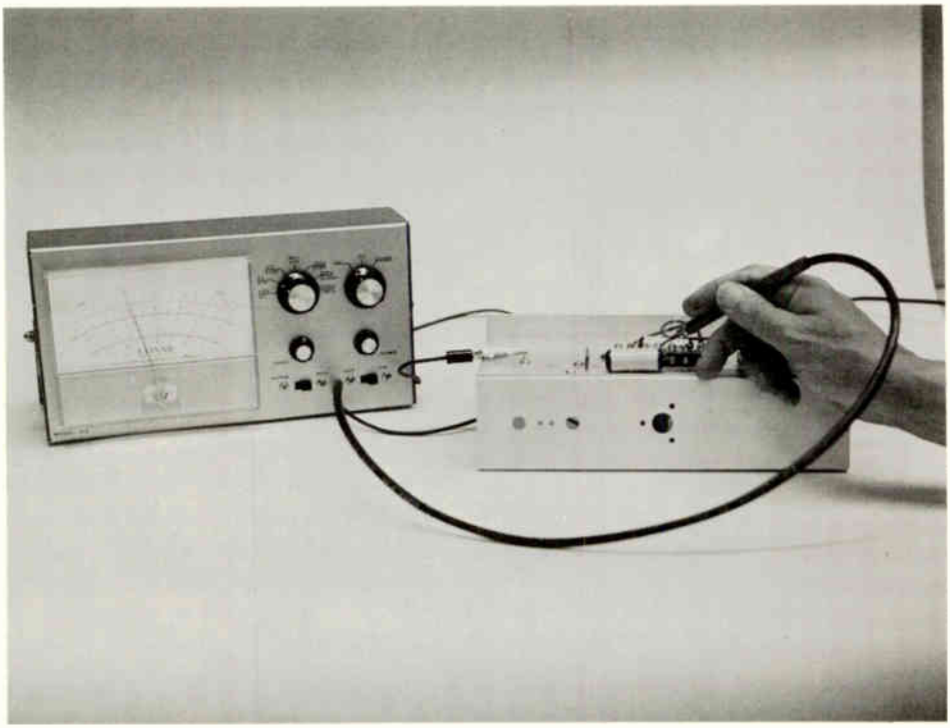
TRAINING KIT MANUAL 3T

PRACTICAL DEMONSTRATIONS OF BASIC ELECTRONICS



The completed tvom being used to make ac measurements.

INDEX OF SECTIONS

JP2M1075 1975 EDITION Litho in U.S.A.

INSTRUCTIONS FOR PERFORMING EXPERIMENTS 21 THROUGH 30

Now that you have experimentally proved Ohm's Law, Kirchhoff's Voltage Law, and Kirchhoff's Current Law for dc circuits, you are ready to prove that the laws also hold for ac circuits. It is extremely important for you to become thoroughly familiar with ac circuits, because they are the ones through which all radio and television signals pass. These experiments, in which you will see for yourself how ac circuits work, are a very valuable part of your training.

To perform these experiments, you will have to measure ac voltages with your tvom. As you already know, your tvom is capable of measuring dc and resistance. You demonstrated this in the previous experiments. In the experiments you are about to perform, most of the measurements to be made are ac measurements.

You have probably been wondering why one of the test leads is very much heavier than the other. It is a special type of low capacity cable known as coaxial cable. It is so designed that a very low capacitance exists between the center conductor and the outer shield braid, which is covered by an insulated coating. With this low capacitance cable, it is possible to measure ac voltages with frequencies up to several thousand kilohertz. The outer braid shield is necessary when using your tvom on the low ac ranges to prevent stray capacitive pick-up.

CONTENTS OF THIS KIT

The parts included in this kit are illustrated in Figs. 1 and 2, and listed in the captions. Check the parts you received against this list to be sure that you have all of them.

If any part of this kit is obviously defective or is damaged in shipment, return it to NRI immediately for replacement, as directed on the packing slip accompanying this kit.

Gather the parts left over from the previous kits and put them in some convenient place. You will need them in your experiments.

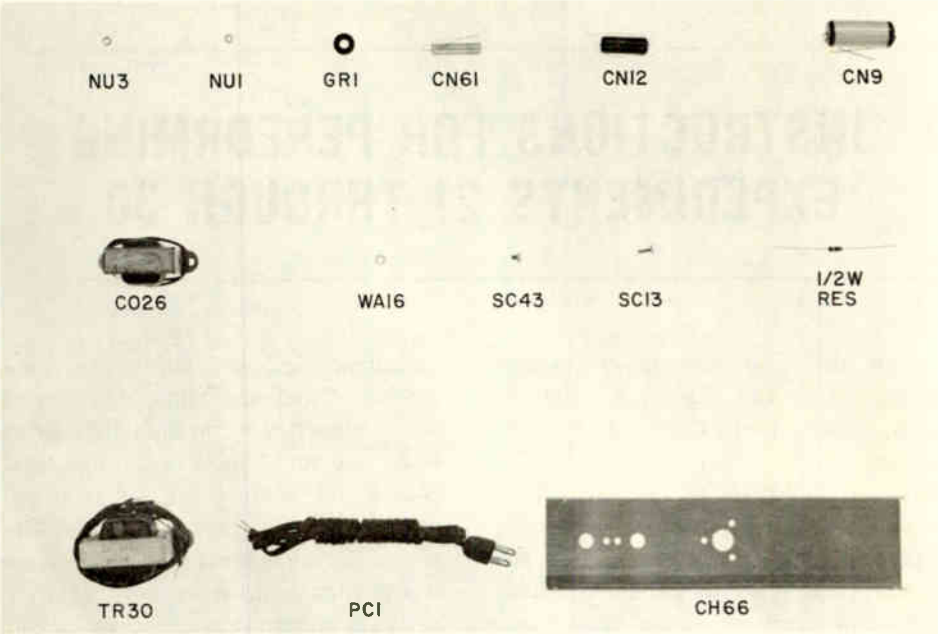


Fig. 1. The experimental parts for this training kit are shown above and listed below.

Quan.	Part No.	Description	Price Each
1	CH66	Chassis rail	.79
2	CN9	.25 mfd tubular cap.	.25
1	CN12	.1 mfd tubular cap.	.18
2	CN61	20 mfd, 150V elect. cap.	.65
1	CO26	Iron core choke coil	1.30
2	GR1	3/8" grommet	12/.25
1	NU1	6-32 hex nut	12/.15
4	NU3	8-32 hex nut	12/.15

Quan.	Part No.	Description	Price Each
1	PC1	Power cord	.40
1	RE27	220-ohm, 1/2W res.	.15
1	RE35	47K-ohm, 1/2W res.	.15
1	RE93	1.8 megohm, 1/2W res.	.15
1	RE102	3K-ohm, 1/2W res., 5%	.24
2	SC13	3/8" X 6-32 screw	12/.15
4	SC43	1/4" X 8-32 screw	12/.25
1	TR30	Power transformer	2.50
4	WA16	No. 8 lockwasher	12/.15

All resistors are 1/2-watt, 10% tolerance unless otherwise specified.

Before you begin your experiments in this Training Kit you will install components on the etched circuit board of your tvom to enable you to read ac voltages. You will also calibrate the ac portion of your tvom, recheck the dc calibration, and install the tvom in its cabinet.

ADDING THE AC FUNCTION TO YOUR TVOM

The parts needed to add the ac function to your tvom are shown in Fig. 2 and listed under the figure. Gather together those parts shown in Fig. 2.

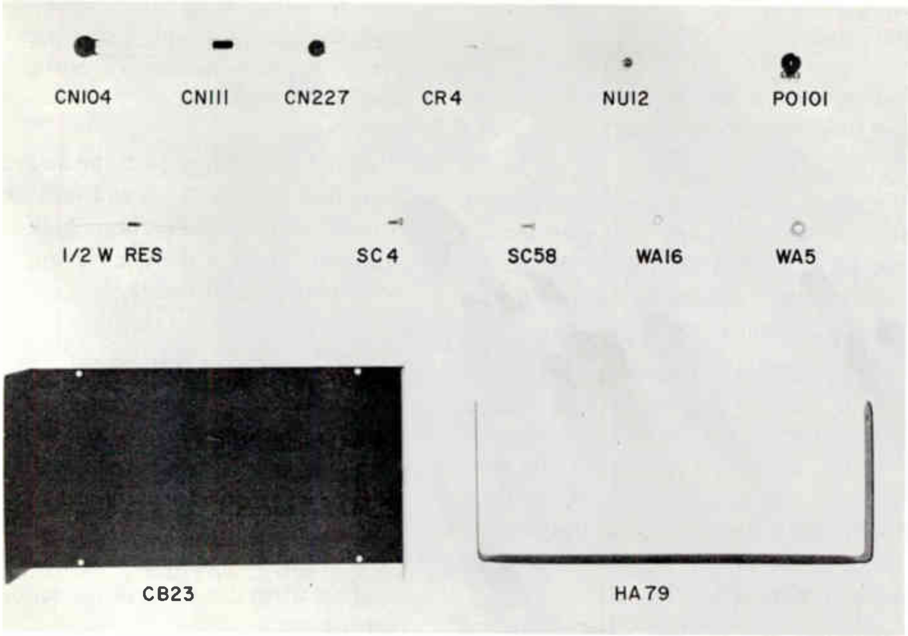


Fig. 2. The ac parts for your tvom are shown above and listed below.

Quan.	Part No.	Description	Price Each
1	CB23	Cabinet	2.95
1	CN104	.1 mfd disc cap.	.36
2	CN111	5 mfd elect. cap.	.35
1	CN227	120 pf disc cap.	.15
4	CR4	1N60 diode	.45
1	HA79	Handle	2.18
2	NU12	8-32 cap nut	12/.25
1	PO101	100K-ohm trimmer pot.	.23

Quan.	Part No.	Description	Price Each
1	RE39	1 megohm, 1/2W res.	.15
1	RE48	2.7K-ohm, 1/2W res.	.15
2	SC4	3/8" X 8-32 screw	12/.15
4	SC58	3/8" X 6-32 thread cutting screw	12/.25
2	WA5	No. 8 flat metal washer	12/.15
2	WA16	No. 8 lockwasher	12/.15

All resistors are 1/2 watt, 10% tolerance unless otherwise specified.

To add the parts to the circuit board, you must first remove the circuit board from its installation behind the panel. First, make sure the meter is "off," then remove the 9V battery and the battery connector . . . . ( )

Remove the two bar knobs from the Range and Function switches and the two round knobs from the Zero and Ohms Adjust controls . . . . ( )

Loosen the two nuts which secure the circuit board to the meter terminals. Be careful not to damage Q_1 and Q_2 . . . ( )

Remove the two nuts that secure the

Range switch and Function switches to the panel . . . . (✓)

Remove the two meter terminal nuts and the two washers . . . . (✓)

The etched circuit board is now free of the panel and may be carefully pulled to the rear of the panel. You may remove the 1.5V "C" cell from its holder to give a little more working room. You do ***not*** have to disconnect any of the wires (✓)

The assembly instructions are given in Fig. 3. The four glass diodes have colored bands at the cathode end and ***must*** be installed as shown in Fig. 3. Be very careful when you bend the diode leads not to bend them too close to the body of the diode or you may break the glass seal and ruin the diode.

Also, be sure to observe the polarity of the two electrolytic capacitors, as you did in the last kit.

When you are sure you know how to mount all the parts, proceed with the assembly instructions in Fig. 3.

After completing the assembly, reinstall the circuit board to the panel and meter. Replace the battery, battery connector and the knobs . . . . (✓)

Before proceeding with the ac calibration, turn the meter on and recheck the Balance and DC calibration. Follow the procedure given in the last training kit to perform these adjustments . . . . (✓)

AC CALIBRATION

After you have checked the dc calibration and balance, you will calibrate the ac portion of the tvom. You will use the voltage at your wall outlet to calibrate your tvom, so you must exercise extreme caution when carrying out the calibration procedures.

Commercial ac voltage, while nominally 117 volts, varies from one part of the country to another, and, indeed, from hour to hour at any given location. These variations are due to the varying demand

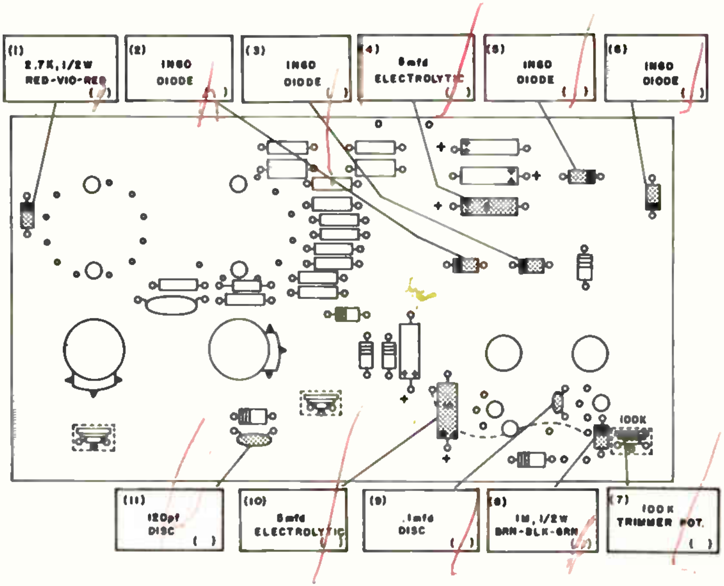


Fig. 3. Steps used for assembling your tvom.

on the power company generators. During high usage times the voltage may drop as low as 95 volts and at other times may rise to 125 volts. The high usage times are around mealtimes (morning, midday, and 6-7 p.m.) and during hot, humid days when many air conditioners are in use. It would be best to perform your calibration at some time ***other*** than these high usage times.

For purposes of calibrating your tvom you can assume the line voltage to be 120 volts and use this value as your calibration reference. To calibrate your tvom, place the meter face up so that you have access to the AC Calibrate trimmer potentiometer through the hole labeled "AC." Set the Range switch to "1200V", the Function switch to "AC", the Polarity switch to "Norm." and turn the meter "ON". Short the probe tip to the ground clip and zero the meter with the Zero adjust control.

With a thin bladed screwdriver, turn the AC Calibrate control fully clockwise (to the right). Now touch the ground clip to the screw head which holds the cover of a wall outlet in place, and insert the probe tip into one of the openings of the ac outlet. If you get no reading at all on your meter, try the probe in the other opening of the ac outlet. When you have found the "hot" opening, remove the probe and ground clip and switch the meter to the "300V" range. You can loosen the screw holding the cover of the ac outlet slightly so that you can clip the ground clip in place without having to hold it. With the ground clip in place, insert the probe tip into the "hot" ac opening and watch the meter. The pointer should move upscale. Adjust the AC Calibrate control until the meter reads 120 volts. (This is the second division after "10" on the 0 to 30 range.)

Remove the probe from the ac outlet and switch to the 120V range. Again insert the probe into the "hot" opening and adjust the AC Calibrate control for exactly full scale.

ASSEMBLING THE CABINET AND HANDLE

To assemble the handle to the cabinet, first place a No. 8 lockwasher over one of the 3/8" X 8–32 screws. Pass the screw through one of the holes in the center of one end of the cabinet from the ***inside*** to the ***outside***. While holding the screw head and lockwasher against the inside of the cabinet, place a No. 8 flat metal washer over the screw, then position the handle so that the screw can also pass through one of the holes in the handle. Secure this assembly temporarily with one of the cap nuts. Tighten only finger-tight for now.

Following exactly the same procedure just described, secure the other end of the handle to the cabinet with a 3/8" X 8–32 screw, No. 8 lockwasher, No. 8 flat washer and a cap nut.

With both ends of the handle fastened, tighten both screws as much as possible. This will secure the handle and yet allow you to move it around to serve as a stand for the completed tvom.

To fasten the cabinet and tvom together, lay the tvom face down on a clean, soft surface such as a tablecloth or bedspread. Put the cabinet into place, being sure that the four small holes in the back of the tvom panel line up with the holes in the cabinet. Now fasten the cabinet to the tvom with the four 3/8" X 6-32 thread-cutting screws. **DO NOT OVERTIGHTEN THESE SCREWS**. The tvom panel is aluminum, and if you overtighten the screws they will probably pull out of the aluminum.

Performing The Experiments

The experiments you are to do will demonstrate many of the basic facts you should know about resistance, inductance, and capacitance, and their effect in ac circuits. Do not skip any of the experiments; each of them is vitally important to your training. Follow the same procedure for carrying them out that you used in the previous manuals.

(1) Check the condition of the tip of your soldering iron. Clean it or retin it, if necessary.

(2) Read the experiment through completely, paying particular attention to the Introductory Discussion and the Experimental Procedure to get an idea of what is to be accomplished.

(3) At the beginning of each section describing the procedure to be followed, we will give you a list of the parts you will need. We will not, however, list the tools, solder, or hookup wire you will need. Just remember to keep them handy and to have your soldering iron ready.

We will not give the color code of the various resistors you will need. By this time you should be familiar enough with the resistor color code to select the correct ones. Gather the parts listed at the start of each experimental procedure from the parts you received in this kit and those left over from earlier kits.

(4) With the parts at hand, and with your soldering iron hot and ready for use, read the experiment again, this time carrying out the instructions exactly as given and in the order listed. Record all data in the tables provided, make the necessary computations, and prepare any graphs that are required.

(5) Read the Discussion of the experiment. If your experimental results don't seem to be right, repeat the experiment.

IMPORTANT: If you cannot do an experiment successfully, don't just give up and go on to the next one. Reread the experiment carefully to be sure you are performing it correctly. Look for loose solder joints, incorrect connections, or wrong parts. If you cannot find the trouble, write to us on the special consultation blank you received with this kit.

Give an accurate and complete description of the action that takes place and include the results of any measurements you have made that have a direct bearing on the problem. Be sure to tell us exactly which experiment you are working on and the step or steps in the experiment that you can't carry out successfully so that we can help you as quickly as possible.

(6) Read the instructions for each Statement carefully. Carry out any experimental procedures required. Read the Statement carefully, and put a circle around the choice that best completes the Statement according to your findings. Then, on the Report Sheet, write the statement number and your choice(s) for the Statement. When you have finished all the Statements, fill in the rest of the spaces as instructed on the Report Sheet, and send in the Report Sheet to NRI for grading.

At this point, you should have a solder lug, three terminal strips, a 500K-ohm potentiometer with on-off switch, and two series-connected flashlight cells mounted on your chassis (Fig. 4).

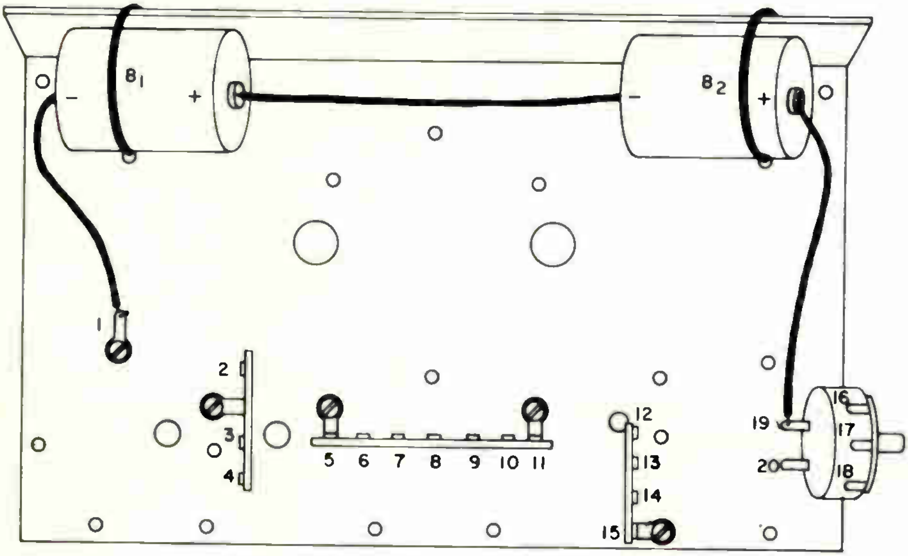


Fig. 4. Chassis before Experiment 21.

EXPERIMENT 21

Purpose: To show that the period of time required to charge or discharge a capacitor through a resistance depends upon the values of the resistance and the capacitance.

Introductory Discussion: As you learned in your regular lessons, a momentary surge of current takes place when the terminals of a charged capacitor are connected together. The period of time that this current flows is usually too brief to have any practical value, except when high currents over short periods of time are required, as in some forms of electric welding. However, if the rate of charge and discharge can be controlled, the practical applications are almost unlimited. The operation of the sweep circuits that move the electron beam in the picture tube of a TV receiver is a practical example of the charging and discharging of a capacitor.

In this experiment, we will show that the rate at which a capacitor charges or discharges depends upon the amount of resistance in the circuit as well as on the capacitance. Thus, with any given capacitor value, we can control the rate of charge and discharge by changing the resistance in the circuit. The time in seconds required for a capacitor to charge up to 63% of the applied voltage, or discharge to 37% of the applied voltage, is equal to the product of the resistance in megohms and the capacitance in microfarads. This is known as the "time-constant" of the combination.

In this experiment, you will show the effect on the time-constant of changing the resistance in the circuit.

Experimental Procedure: To perform this experiment, in addition to your experimental chassis and your tvom, you will need the following parts.

2 .25-mfd paper capacitors
1 1.8-megohm resistor

Step 1. To charge a .5-mfd capacitor through a 12-megohm resistance.

The circuit we will use is shown in Fig. 21-1. The 12-megohm resistance is the internal resistance of your tvom. For the 3-volt source, you will use the series-connected flashlight cells.

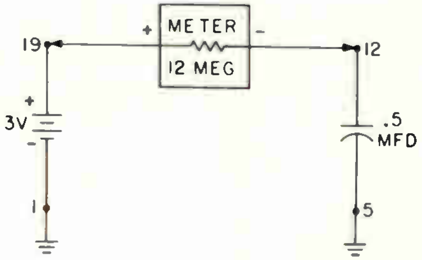


Fig. 21-1. Charging a capacitor through a resistance.

To get the .5-mfd capacitance, we will use two .25-mfd capacitors. As you have learned in your regular lessons, when two capacitors are connected in parallel, the total capacitance is the sum of the capacitance of the individual capacitors. Therefore, two .25-mfd capacitors in parallel will give us .5 mfd.

First, connect the two .25-mfd capacitors in parallel from terminal 5 to terminal 12, as shown in Fig. 21-2. Solder both connections.

Arrange the capacitors so their leads do not touch the chassis. Then short-circuit their leads for a few moments with a screwdriver to be sure they are fully

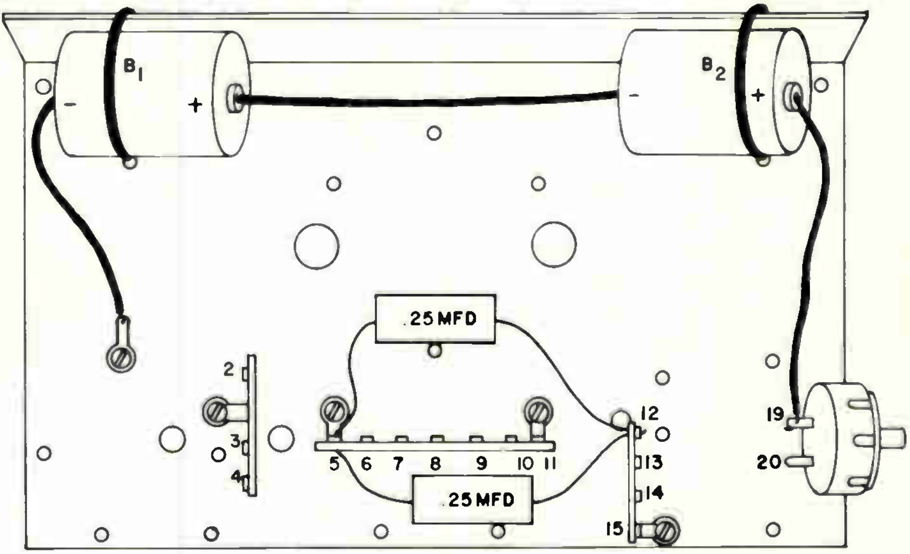


Fig. 21-2. Record results for Experiment 21 here.

discharged. Touch the screwdriver blade to terminal 12 and the chassis at the same time. Do not touch the capacitor leads while doing this experiment or the resistance of your body will affect your reading.

Now, be sure you still have the flashlight cells connected in series with the negative terminal grounded to terminal 1, and the positive lead connected to terminal 19 of the ON-OFF switch, as shown in Fig. 21-2. The battery connects to the capacitor leads at terminal 5 through the chassis ground.

Turn your tvom on to dc; turn the range switch to 3V, and set the polarity switch to normal. Then clip the ground lead to terminal 12, and touch the probe to the positive battery terminal (or terminal 19), and watch the meter pointer.

The meter pointer will move rapidly to the extreme right-hand end of the 3V scale, and then move gradually back toward 0.

To find the time-constant, you will count the number of seconds it takes for the capacitor to reach 63% (approximately two-thirds) of full charge. Since the full voltage is 3 volts, two-thirds will be 2 volts.

Here, the meter is actually indicating the voltage across the 12-megohm input resistance of the tvom. As you have learned, the sum of the voltage drops in a series circuit is equal to the source voltage. Therefore, when you first connect the circuit, the voltage across the resistance of the tvom will be the full 3 volts, making the meter pointer swing all the way over to the right. Then, as the capacitor charges, the voltage across the resistance gradually decreases. When the voltage across the resistance is 1 volt, you know there must be 2 volts across the capacitor, so you count the number of seconds it takes for the meter pointer to move from 3 to 1 on the 3-volt scale.

STEP	MEASUREMENT	YOUR TIME IN SECONDS	COMPUTED TIME IN SECONDS
1	CHARGING .5 MFD THROUGH 12 MEGOHMS	6	6
2	DISCHARGING .5 MFD THROUGH 12 MEGOHMS	5	6
3	CHARGING .5 MFD THROUGH 1.5 MEGOHMS	1	.75
4	DISCHARGING .5 MFD THROUGH 1.5 MEGOHMS	1	.75

Fig. 21-3. Record results of Experiment 21 here.

You can estimate the time in seconds by counting at a normal speaking rate as follows: "one hundred and one," "one hundred and two," etc. The length of time it takes to speak the words will be very close to one second. If you practice counting while watching the second hand of a watch or clock, you can do this very accurately. Record in Fig. 21-3 the number of seconds it takes the meter pointer to move from 3 to 1.

We can compute the time-constant mathematically by multiplying the resistance in megohms by the capacitance in microfarads. This would be 12 X .5, or 6 seconds. Compare the time you estimated with this computed time.

Step 2. To discharge the .5-mfd capacitance through the 12-megohm resistance.

Leave the circuit as it was in Step 1, and hold the meter probe on terminal 19 until the meter pointer swings all

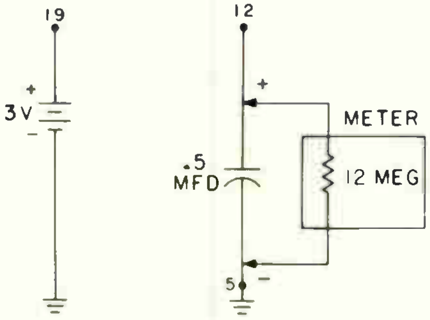


Fig. 21-4. Measuring the voltage across the capacitors as they discharge through the meter resistance.

the way to zero. At that point the capacitors will be fully charged.

Remove the probe from terminal 19. Switch the polarity switch on your tvom to reverse and touch the probe to the chassis ground. You should have the circuit shown in Fig. 21-4.

With the meter connected this way, you are measuring the voltage across the capacitors. As they discharge, the meter pointer will move from 3 down to 0. You want to know how long it takes for the capacitors to discharge to 37% of full charge. This is approximately two-thirds, so you count the number of seconds it takes for the pointer to reach 1 on the 3-volt dc scale. Record your reading in Fig. 21-3.

Step 3. To charge the .5-mfd capacitance through a lower resistance.

We will use the circuit shown in Fig. 21-5, in which we have a 1.8-megohm resistor in parallel with the resistance of the meter. As you have learned, when two resistors are connected in parallel, the combined resistance is less than that of the smaller resistor. In this case, the total resistance will be approximately 1.5 megohms. (You can place an alligator clip on your tvom probe for convenience in making the measurements.)

Connect the positive tvom lead to terminal 20. Set the polarity switch to normal. Connect and solder the 1.8-megohm resistor from terminal 12 to terminal 20. (See Fig. 21-2.) Then, clip the negative test lead of your tvom to terminal 12.

Turn the switch on by rotating the 500K-ohm potentiometer shaft clockwise and watch the meter. As in Step 1, the meter pointer will swing over to 3, and then move back toward 0. This time notice that the meter pointer moves from 3 to 1 so rapidly that it is difficult to estimate the time.

To compute the time-constant, we multiply 1.5 megohms times .5 microfarad, which gives us .75, or less than one second for the time-constant. Estimate the time-constant of the combination you have, and record your result in Fig. 21-3.

Step 4. To discharge the .5-mfd capacitor through the 1.5-megohm resistance.

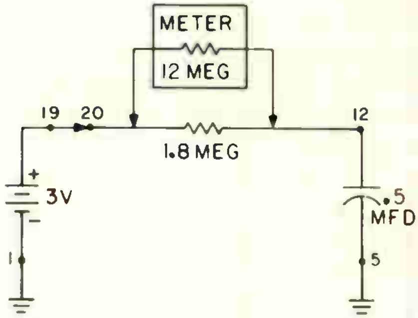


Fig. 21-5. Charging the capacitor through a lower resistance.

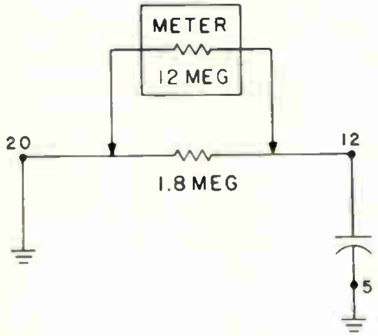


Fig. 21-6. Circuit for discharging the capacitor through a lower resistance.

With the circuit as in Fig. 21-5, leave the switch on until the capacitors are fully charged (until the meter pointer moves all the way to 0). Then, turn the switch off and set the polarity switch on your tvom to reverse. The circuit for this step is shown in Fig. 21-6. To see how long it takes the capacitors to discharge to one-third, short terminal 20 to the chassis with a screwdriver to complete the circuit shown in Fig. 21-6 and count the time it takes the pointer to move from 3 to 1. Again, record the time in Fig. 21-3. It should be the same as the time for Step 3 – less than one second.

Discussion: In Steps 1 and 2 of this experiment you saw that for a given capacitance and resistance in a circuit, the time it takes the capacitor to charge to 63% of full charge is the same as the time it takes it to discharge to 37% of full charge. This time, in seconds, is called the time-constant. It can be computed by multiplying the capacitance in microfarads and the resistance in megohms.

In Steps 3 and 4, you demonstrated that decreasing the resistance in the circuit caused the time-constant to decrease. If you had increased the resistance, the time-constant would have increased.

Instructions for Report Statement No. 21: In this experiment you showed that decreasing the resistance in the discharging circuit of a capacitor reduces the time-constant of the circuit. It can also be shown that decreasing the capacitance of the capacitor without changing the resistance reduces the time-constant.

For the Statement you will prove this by reducing the capacitance to .125 mfd by connecting the two .25-mfd capacitors in series. When two capacitors having the same value are connected in series, the combined capacitance is equal to half the capacitance of one alone.

Unsolder and lay aside the 1.8-megohm resistor and unsolder one end of one capacitor from terminal 5, but leave the other capacitor lead connected to terminal 12. Solder the free lead to terminal 20.

Set the polarity switch on your tvom to normal, and clip the negative test lead to terminal 5. Clip the probe of your meter to terminal 20. Turn the switch on to complete the circuit shown in Fig. 21-7. When the meter pointer goes all the way to 3, the capacitors are fully charged.

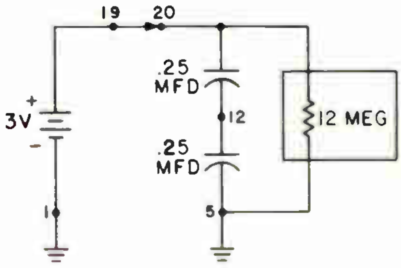


Fig. 21-7. Circuit for connecting capacitors in series.

Turn the switch off, but leave the probe clipped to the capacitor lead. Count the time it takes for the meter pointer to move from 3 down to 1. Then, answer the Statement below and on the Report Sheet.

Turn off the tvom, and unsolder and remove the capacitors from your chassis and store them for future use.

Statement No. 21: When I discharged the .125-mfd capacitance through the 12-megohm input resistance of the tvom, I estimated that the meter pointer dropped from 3 volts to 1 volt:

(1) instantly.
[✓ *(2) in about two seconds.*]
(3) in about ten seconds.

EXPERIMENT 22

Purpose: To show that when a dc voltage is applied to an electrolytic capacitor, the connections must be made with the proper polarity to prevent excessive leakage.

Introductory Discussion: As you learned in your lesson on capacitors, an electrolytic capacitor is quite different in many respects from paper or mica capacitors. One very important difference is that the dielectric in an electrolytic is a very thin film of aluminum oxide that has been formed on the anode by electrochemical action during manufacture. The insulating properties of this oxide depend on the amount of voltage used to form it initially, the amount of voltage applied to the capacitor in use, the temperature, the type of material used for the electrodes, and the kind of electrolyte used.

At best, the dielectric in an electrolytic capacitor is not a perfect insulator, so there will always be some current flow through the dielectric whenever voltage is applied to the capacitor. In a good capacitor, this current flow will be small if the voltage is applied with the proper polarity (the negative terminal of the voltage source connected to the negative terminal of the capacitor and the positive terminal of the source connected to the positive terminal of the capacitor). If the voltage is applied with the wrong polarity, the oxide film will break down. The unit will then cease to act as a capacitor and will instead act as a very low resistance. Pure ac voltage is constantly changing in polarity. Therefore, it should never be applied to an electrolytic capacitor.

The oxide film will also be destroyed if too high a voltage is applied to an electrolytic capacitor, even if the polarity of the voltage is correct. An electrolytic capacitor always has a dc working voltage rating that shows the maximum voltage that can be continuously applied to the capacitor without causing it to break down. Whenever you find it necessary to replace such a capacitor, make sure that the voltage rating of the replacement is at least as high as that of the original.

In this experiment, you will prove that an electrolytic capacitor passes direct current, and that the amount of current passed depends on the polarity of the applied voltage. Because the dc source voltage you have available is low, the current may be rather small when the voltage is applied with the correct polarity. In fact, the current may be too low to be detected with the equipment you have. The characteristics of your particular electrolytic will also affect the amount of current. Some capacitors have higher leakage currents than others, even though they are normal in all other respects. What we want you to observe in this experiment is that reversing the polarity of the source voltage changes the current through the capacitor.

Each of the electrolytic capacitors sent to you in this kit is made in dry form (that is, it contains a paste electrolyte). Its schematic symbol is the same as the symbol for any other capacitor except that it has a + sign near the positive lead.

Experimental Procedure: For this experiment, you will need your experimental chassis, tvom, and the following parts:

2 20-mfd electrolytic capacitors
1 47K-ohm resistor

Fig. 22-1. Schematic showing an electrolytic capacitor in series with a resistor and a battery.

Turn your tvom on; set the polarity, range and function switches to measure +3V dc.

It is desirable to make as many measurements as possible in any given experiment on the same range of your test instrument to avoid errors due to differences between ranges. For example, a dc source may produce exactly full-scale deflection on the 3V range, but a meter

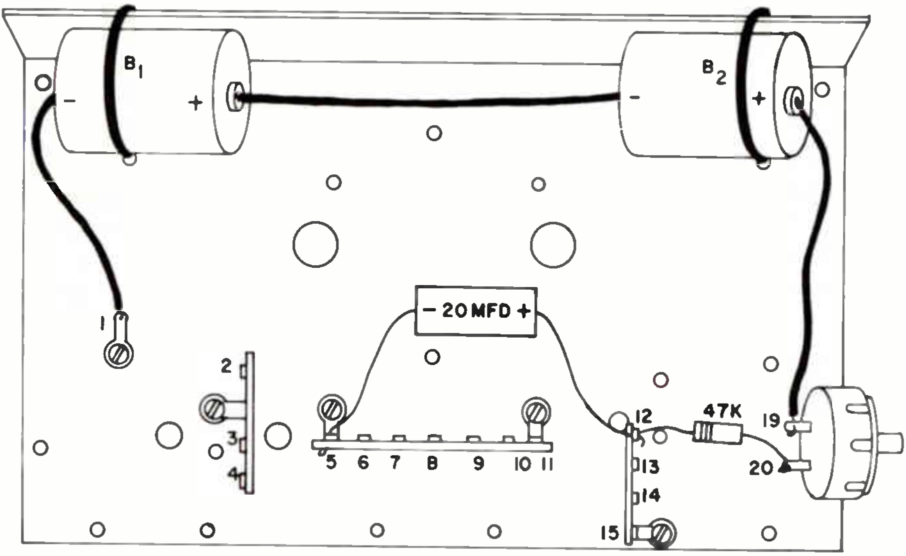


Fig. 22-2. Pictorial of the circuit in Fig. 22-1.

reading of 2.5 to 3.5 volts on the 12V range. Such variations are well within normal tolerances, and for ordinary purposes could be overlooked. However, they may prove troublesome when you are performing experiments that require accurate readings. Remember, the maximum tolerance of the meter movement alone is about 2 or 3 percent of the full-scale value. Also, the resistors in the voltage divider network of the tvom have a 1% tolerance, so a slight difference in reading on two ranges could occur even with everything normal. Using a single range whenever possible removes this cause of error.

The capacitor leads are identified by a + sign or by both + and – markings on the body of the capacitors. Solder the negative lead of one electrolytic capacitor lead to terminal 5. Connect the positive capacitor lead to terminal 12. Connect a 47K-ohm resistor from terminal 12 to terminal 20. Solder the connections.

The circuit for this step is shown in Fig. 22-1. The wiring is shown in the pictorial diagram in Fig. 22-2.

Step 1. To determine how much current flows through the electrolytic capacitor when it is connected with the correct polarity. To do this, you will measure the voltage drop across the 47K-ohm resistor.

Connect the probe of your tvom to terminal 20. Connect the ground clip to terminal 12. Turn the switch on and observe the meter. When the pointer becomes stationary, read the meter. Enter the voltage measured on the top line in Fig. 22-3. Turn off the switch.

Step 2. To determine how much current flows through the electrolytic capacitor when it is connected with the reverse polarity.

STEP	CIRCUIT USED	VOLTAGE
1	+ CAPACITOR LEAD TO + BATTERY TERMINAL	.8V ✓
2	+ CAPACITOR LEAD TO – BATTERY TERMINAL	1.3V

Fig. 22-3. Results of Experiment 22.

Reverse the capacitor connections by unsoldering and interchanging them, so that the positive lead of the capacitor goes to terminal 5 and the negative lead is connected to the 47K-ohm resistor at terminal 12.

Again, turn the switch on and measure the voltage drop across the 47K-ohm resistor. Leave the tvom connected to terminal 12 and to terminal 20 as in the previous step. Enter the voltage reading on the second line of Fig. 22-3. Turn the switch off to open the circuit.

Discussion: The voltage drop across the resistor is produced by the current flowing through the capacitor and the resistor. The amount of current can be found by dividing the measured voltage by 47,000. The current is very small.

Do not conclude from this experiment that the direct current passed by an electrolytic capacitor is negligible, however. Remember, you have a source voltage that is far less than the voltage that is usually applied to a capacitor in a practical circuit. With the normal circuit voltage applied to the capacitor, you could measure the current directly with a milliammeter, instead of using the indirect method you have followed here.

The amount of voltage drop across the resistor in Step 1 will vary with different capacitors. Some of the capacitors that we tried in the NRI laboratory had so little leakage that we were unable to measure any voltage drop at all across the resistor. Do not be concerned, therefore, if your voltage reading for Step 1 is 0.

You should, however, find a definite voltage drop across the resistor after you have reversed the capacitor connections to carry out Step 2. Here again the exact voltage depends on the characteristics of your capacitor, but the voltage should be greater than that measured in Step 1. This increase in voltage represents a corresponding increase in the current in the circuit; therefore, you have shown that the amount of current through the capacitor depends upon the polarity of the capacitor.

Because of this characteristic of electrolytic capacitors, be sure that you connect them with the proper polarity (positive terminal of the capacitor to positive terminal of the voltage source) when you install them in a circuit. Furthermore, you must not apply an ac voltage to an electrolytic capacitor unless the ac is superimposed on a larger dc voltage so that the total voltage applied to the capacitor never reverses itself.

Instructions for Statement No. 22: In the experiment for this Statement, you are to find out whether or not the capacitance of an electrolytic capacitor has any effect on the leakage current produced by connecting the capacitor with the wrong polarity.

Connect the two 20-mfd electrolytic capacitors in parallel. Solder the positive leads of both capacitors to terminal 5. Then, solder the negative capacitor leads to terminal 12. This puts the two capacitors in parallel, giving a capacitance of about 40 mfd. The circuit for this statement is shown in Fig. 22-4.

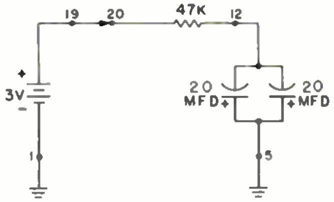


Fig. 22-4. The two capacitors are connected in parallel and placed in series with the resistor.

To measure the voltage drop across the 47K-ohm resistor, connect the probe of your tvom to terminal 20, and the ground clip to terminal 12. Turn the switch on and take a voltage reading. Compare this reading with the voltage for Step 2. 1.5V Choose the answer to the Statement below, and also on the Report Sheet that most nearly corresponds to the results of your comparison. Turn the switch off and disconnect the tvom leads.

Unsolder and remove the 47K-ohm resistor and the electrolytic capacitors. Leave the flashlight cells in place, but unsolder the positive lead from terminal 19.

Statement No. 22: When I connected the two capacitors in parallel, the leakage current (as indicated by the voltage drop across the resistor):

(1) remained unchanged.
[✓ *(2) increased.*]
(3) decreased.

Building An AC Voltage Divider

To do the rest of the experiments in this kit, you must have a source of ac voltage with some way of adjusting the output. You will use the 117 volts supplied by the ac power line and a transformer to produce about 12 volts across a potentiometer. By adjusting the potentiometer, you will be able to get the exact voltage needed for the experiments.

To build this assembly, you will need:

1	Power transformer (TR30)
1	Chassis rail (CH66)
1	1K-ohm potentiometer (PO7 from Kit 1)
2	3/8" rubber grommets (GR1)
2	1/4" X 8-32 screws (SC43)
2	3/8" X 6-32 screws (SC13)
2	8-32 hex nuts (NU3)
1	6-32 hex nut (NU1)
2	No. 8 lockwashers (WA16)
1	5' power cord (PC1)

The transformer and potentiometer will be mounted on the chassis. The transformer will be mounted in its permanent location on the underside of the chassis plate. Fig. 5 shows where to mount the parts. Fig. 11 of your IT Manual shows the hole locations. The power transformer is represented by the broken lines.

Install the rubber grommets in holes E and J, which are the large holes near the middle of your chassis plate. Squeeze one of the grommets into an oblong shape and push it into one of the holes so that the hole in the chassis fits into the groove in the grommet. Install the second grommet in the same manner.

Place the power transformer on your worktable with its mounting feet up. Push the two green leads and the green/yellow lead of the transformer through the grommet (shown in Fig. 5) in hole J

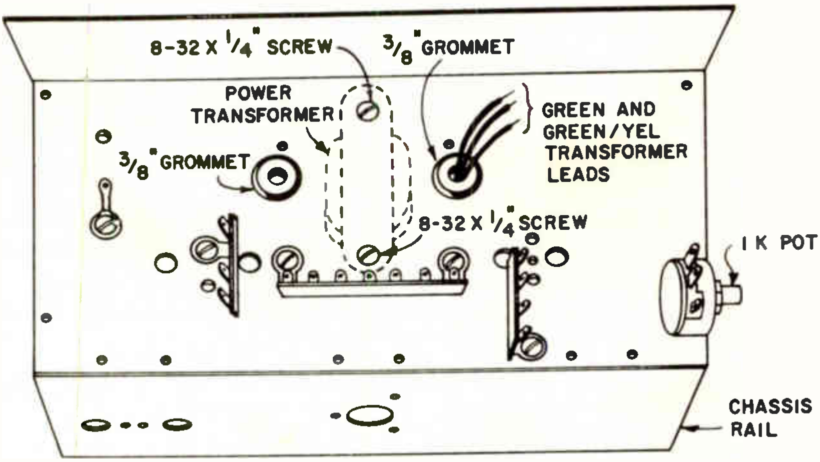


Fig. 5. Mounting the parts.

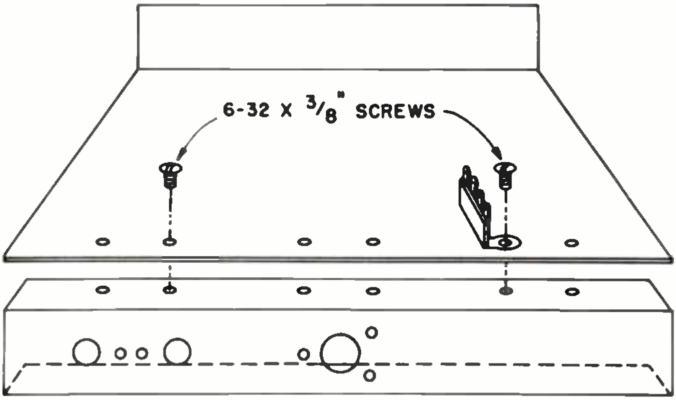


Fig. 6. Mounting the chassis rail.

from the underside of the chassis. Line up the mounting holes in the chassis, holes G and H, over the mounting feet in the transformer. Attach the transformer to the chassis with two 1/4" X 8-32 screws, two No. 8 lockwashers and two 8-32 hex nuts.

Remove the 500K-ohm potentiometer with On-Off switch and replace it with the 1K-ohm potentiometer (PO7).

Position the 1K-ohm potentiometer so that its terminals are pointing upward, and tighten the mounting nut.

Mount the chassis rail along the front edge of the chassis. Turn the rail so that the lip having six holes in it is up. These six holes mate with the six holes in the edge of the chassis, as shown in Fig. 6. Remove the screw holding the 4-lug terminal strip and replace it with the 3/8" X 6-32 screw. Pass the screw through the mounting foot in the terminal strip, the hole in the chassis and the mating hole in the chassis rail. Attach a nut and tighten.

Pass a 3/8" X 6-32 screw through the second hole from the left side of the chassis and the mating hole in the chassis rail. Attach a nut and tighten.

During the remainder of this kit, the chassis will be supported by the chassis rail and the power transformer.

WIRING THE AC CIRCUIT

Connect the power cord to the **BLACK** power transformer leads. Separate the two conductors at the end of the power cord. Connect each conductor to a black transformer lead. Solder both connections and wrap them with electrical tape.

Carefully wrap the bare ends of the two red and the red/yellow power transformer leads with tape. Do not connect these leads together. Coil them up near the chassis as these leads will not be used in this kit.

On the top of the chassis, make the following temporary connections which are shown in Fig. 7. Connect and solder one green power transformer lead to terminal 11. Connect the other green transformer lead to terminal 12. Connect and solder the green/yellow transformer lead to terminal 9.

Cut a 3" length of hookup wire and

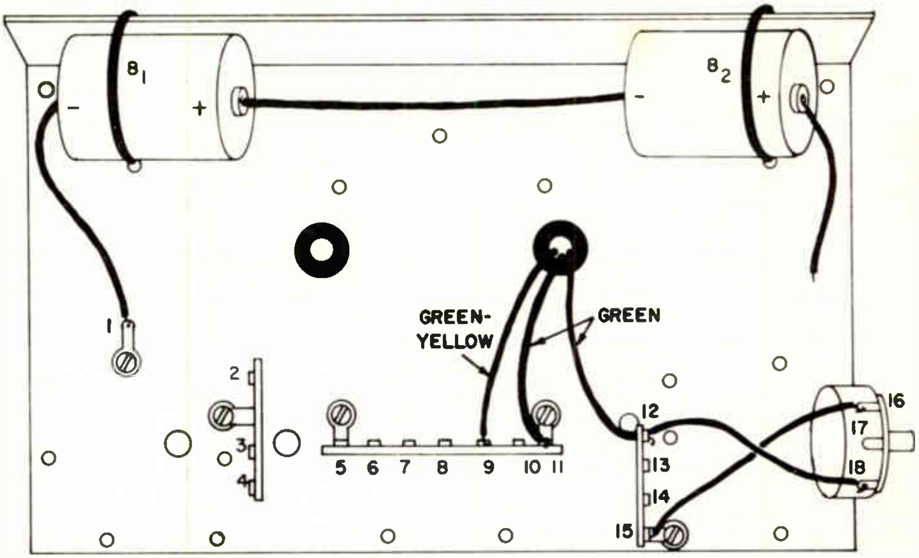


Fig. 7. Wiring the ac voltage divider.

remove 1/4" of insulation from each end. Using temporary connections, connect this wire from terminal 12 to terminal 18 on the 1K-ohm potentiometer.

Prepare a 4" length of hookup wire. Connect it from terminal 15 to terminal 16. Solder both connections. Check to see that your circuit is wired according to Fig. 7.

The schematic of the circuit you have wired is shown in Fig. 8.

Caution: It is extremely important that you perform all ac experiments on an insulated work surface. An ordinary wooden table, either bare or covered with linoleum or oilcloth, is ideal. A porcelain-top table is unsatisfactory, because the porcelain is applied over a metal base. For safety's sake, you should perform all experiments where you will not be able to touch any grounded object, such as a radiator, a water pipe, or a damp concrete basement floor. If you must carry out your experiments in the basement, be sure that you always stand on a dry board while working on the ac supply.

Be sure to disconnect the plug from the ac line before making changes in your circuit or before moving the meter lead clipped to a terminal or lead.

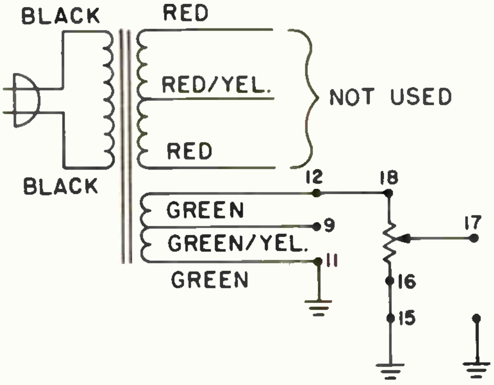


Fig. 8. Schematic diagram of the ac voltage divider circuit.

EXPERIMENT 23

Purpose: To show that a capacitor will block dc but will pass ac.

Introductory Discussion: A capacitor is a device for storing electrical energy. It cannot do this, however, unless the dielectric used to separate the plates has certain characteristics, the most important of which is that it must electrically insulate the plates from each other.

It might seem that insulating the plates so that there is no conductive path between them would block the flow of an electric current completely. However, as you have learned from your course, this is not true. Although a capacitor does block direct current, it passes ac in the circuit. You are going to demonstrate these capacitor actions experimentally.

To demonstrate the insulating properties of a capacitor with a solid dielectric, you will measure the current through the capacitor for each type of voltage. Your tvom will not measure current directly. You must determine the current in a circuit indirectly by measuring the voltage across a resistor in the circuit, and then dividing the measured voltage by the resistance across which you measured the voltage. The result will be the current in amperes. This is the same method you used to determine the current in the last experiment.

You learned that pure ac should not be applied to an electrolytic capacitor. The reversing ac voltage will either put a positive potential on the negative plate of the capacitor or a negative potential on the positive plate of the capacitor. When this wrong polarity is applied to the oxide film dielectric of an electrolytic capacitor, the dielectric breaks down, causing leakage between the capacitor plates. However, an electrolytic capacitor can be safely used to pass ac if we also apply a dc potential of the correct polarity to the capacitor. By doing this, we no longer have pure ac. Instead, we have dc with an ac component superimposed on the dc. The voltage across the capacitor plates does not reverse polarity and the dielectric does not break down.

To demonstrate a circuit condition having ac superimposed on dc, you will connect the 3-volt battery into a circuit with the electrolytic capacitor and measure the dc and ac voltages.

You will determine the peak-to-peak value of the ac voltage applied to the capacitor. Knowing the peak-to-peak amplitude of the ac waveform enables you to compare the ac component with the dc component. From your studies in the regular lessons, you know that the ac scales on your tvom indicate the effective or rms value of the ac waveform.

To refresh your memory, examine the ac waveform shown in Fig. 23-1A. It shows one cycle of an ac voltage having an effective value of 1 volt. Notice that the waveform rises to a peak value of 1.4 volts above zero on the positive half-cycle and to -1.4 volts on the negative half-cycle. The total height of the waveform from the negative peak to the positive peak is twice the peak value, or 2.8 volts peak-to-peak.

Now let's superimpose this ac waveform on a dc voltage as shown in Fig. 23-1B. The figure shows +2 volts dc with a 1 volt ac waveform varying above and below the 2 volt level. Notice that with 1 volt ac superimposed on 2 volts dc, the resultant voltage never goes to zero. When

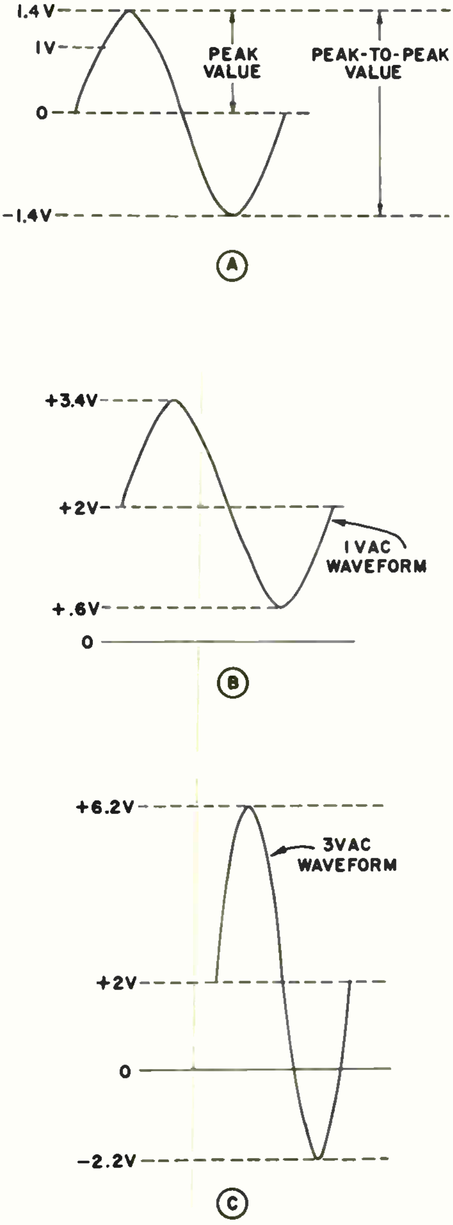


Fig. 23-1. Waveform of 1 volt (effective) with peak value and peak-to-peak value indicated (A); 1 volt ac superimposed on +2 volts dc (B); 3 volts ac superimposed on +2 volts dc (C).

the 1 volt ac waveform is zero, the resultant voltage is 2 volts, or the value of the dc voltage alone. When the ac waveform rises to a peak of 1.4 volts, the resultant voltage is 3.4 volts, or the su of the peak voltage plus the dc value. When the waveform falls to its lowest value, the resultant voltage is the difference between the peak value and the dc value, or 2 – 1.4 = 0.6 volt. From this you can see that the voltage never goes to a negative value.

A large ac waveform superimposed on a dc voltage can cause the voltage to reverse if the peak of the ac value is greater than the dc voltage. Fig. 23-1C shows a 3-volt ac waveform superimposed on +2 volts dc. Again the instantaneous values of the ac voltage combine with the dc voltage to produce the resultant voltage. The peak value (one-half the peak-to-peak value) of a 3-volt ac waveform is 4.2 volts. When the ac waveform reaches its maximum negative peak, the resultant voltage goes to a negative value, or -2.2 volts. Thus, the resultant voltage reverses its polarity for a small portion of the ac cycle.

From this discussion you can see that if we apply a dc potential of the proper polarity to the plates of the electrolytic capacitor we can prevent an ac voltage from reversing the polarity on the plates of the capacitor. Also you can see that we know what value of dc will be needed to prevent a given ac waveform from reversing the polarity on the capacitor plates.

In these experiments, we have placed resistors in the circuits where current values must be determined. However, in actual service work, if there is no suitable resistance in the circuit, one can be inserted. If you do this, you must be careful to choose a suitable value. Too low a resistance will not develop a measurable voltage when a small current flows through it, and too high a resistance will change the total impedance of the circuit enough to cause a significant decrease in the amount of current.

Experimental Procedure: For this experiment, you need your experimental chassis, your tvom, and:

1 18K-ohm resistor
1 .25-mfd capacitor
1 1K-ohm resistor
1 20-mfd electrolytic capacitor

Wire the circuit shown in Fig. 23-2. The chassis layout is shown in Fig. 23-3. Connect the 18K-ohm resistor from terminal 11 to terminal 14 and connect a .25 mfd capacitor from terminal 14 to terminal 13. Solder all three connections.

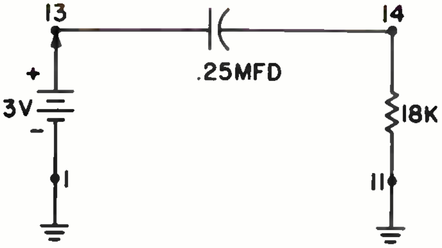


Fig. 23-2. Schematic of circuit used to measure current through the capacitor.

Step 1. To measure the dc voltage drop across the 18K-ohm resistor.

First set up your tvom for use as a dc voltmeter. Set the function switch to dc, the range switch to 3V and set the polarity switch to normal. Connect the

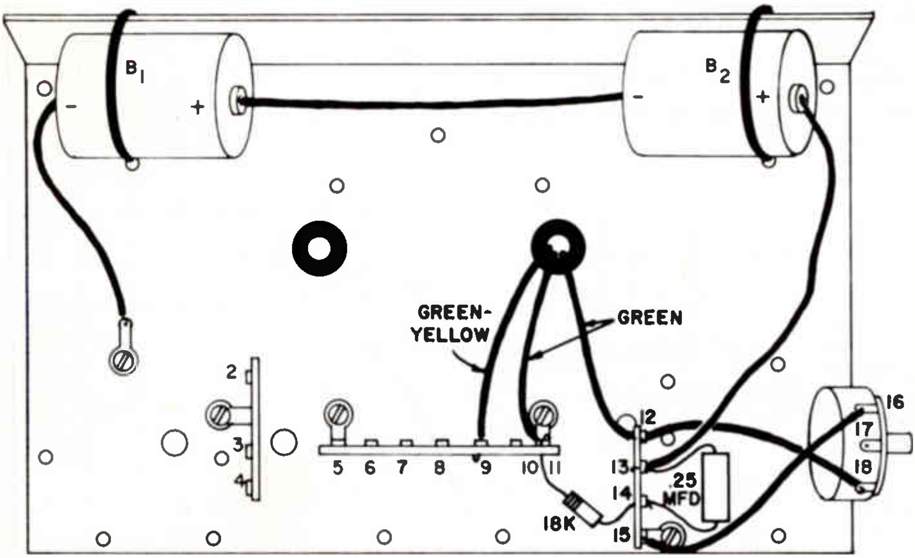


Fig. 23-3. Circuit wired for Step 1.

VOLTAGE ACROSS RESISTOR	
STEP 1 DC	0
STEP 3 AC	2.55V

Fig. 23-4. Results of Steps 1 and 3.

ground clip of your tvom to the chassis and clip the probe to terminal 14. Touch the positive battery lead to terminal 13 and read the voltage. The reading will depend upon the characteristics of your particular capacitor. Ideally, it should be zero, but an imperfect dielectric or leakage along the outside of the capacitor case may allow enough current through the circuit to give you some small reading. Record your reading on the top line of Fig. 23-4.

Remove the positive battery lead from terminal 13 and disconnect your tvom from terminal 14.

Step 2. To apply an ac voltage to the resistor-capacitor network that you used in Step 1.

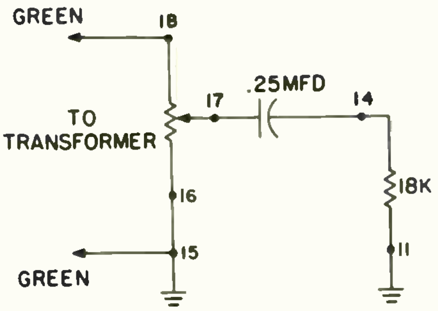


Fig. 23-5. Schematic of the circuit in Fig. 23-4.

Unsolder and disconnect the lead of the .25-mfd capacitor from terminal 13. Solder the capacitor lead to terminal 17, which is the center terminal of the 1K-ohm potentiometer.

Position the resistor and the capacitor so that their leads cannot touch any of the exposed terminals or the metal chassis. The circuit is shown in schematic form in Fig. 23-5.

Now, prepare your tvom for making ac measurements. Set the function switch to ac and the range switch to 12V. When measuring ac or dc voltages on this range, read the meter scale that is numbered from 0 to 12. The reading is given directly in volts.

Clip the ground lead of your tvom to the chassis. Plug the power cord from your experimental chassis into an ac receptacle.

Hold the probe by the insulated handle so as not to touch the metal tip. Touch the meter probe to the center terminal (terminal 17) of the potentiometer, and rotate the control shaft of the potentiometer with your fingers until the meter pointer indicates less than 3 volts. Now turn the range switch on the tvom to the 3V position, and carefully adjust the potentiometer to give you a reading of exactly 3 volts.

Your voltage divider will now have an output voltage that is equivalent to the dc voltage you used in Step 1 of this experiment.

Step 3. To measure the voltage across the 18K-ohm resistor.

Leave the ground clip of the tvom clipped to the chassis. Touch the probe to terminal 14, and read the 3-volt scale of the meter. Record the meter reading in Fig. 23-4 as the voltage across the resistor in Step 3.

Remove the plug from the ac outlet. Disconnect the tvom test probes from the circuit. Unsolder and remove the .25-mfd capacitor. Unsolder and remove the lead of the 18K-ohm resistor from terminal 11 and connect this lead to terminal 8.

Step 4. To apply both ac and dc to a circuit containing the electrolytic capacitor.

You will use the circuit shown in Fig. 23-6. Solder the negative lead of the 20-mfd electrolytic capacitor to terminal 17 of the ac voltage divider. Solder the positive lead of the electrolytic capacitor to terminal 14 and the lead of the 18K-ohm resistor.

Solder the positive battery lead to terminal 8. If necessary, splice a piece of hookup wire to the lead. Check your work against Fig. 23-6.

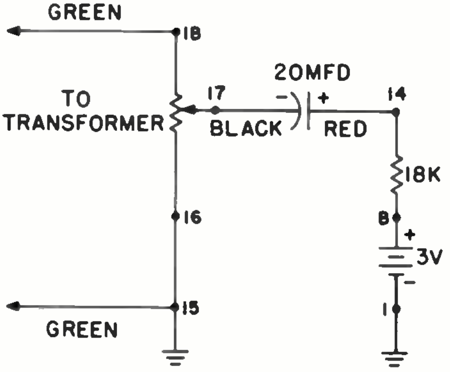


Fig. 23-6. Schematic of the circuit for Step 4.

	DC	AC	PEAK TO PEAK
BATTERY VOLTAGE	3V	☒	☒
VOLTAGE ACROSS 18K-OHM RESISTOR	0	1	2.8
VOLTAGE ACROSS CAPACITOR	3V	0	[illegible]0

Fig. 23-7. Record the values measured in Step 4.

Clip the ground lead of the tvom to the chassis. Set the function switch to dc and the range switch to 3V. Touch the probe to the positive terminal of the battery. Record the voltage in the space provided in Fig. 23-7. Move the ground clip to terminal 14. Touch the probe to the other lead of the 18K-ohm resistor at terminal 8. Record the reading in the space provided in the dc column in Fig. 23-7. This reading should be very nearly zero and indicates the amount of leakage through the electrolytic capacitor.

Clip the ground lead of your tvom to terminal 17 of the ac voltage divider. Touch the probe to the junction of the capacitor lead and the 18K-ohm resistor at terminal 14. Record your reading in the dc column of Fig. 23-7 for the voltage across the capacitor.

Set the function switch to ac and the range switch to 12V. Plug the power cord into the ac receptacle. Touch the probe to the chassis. Adjust the potentiometer until the meter indicates less than 2 volts on the 12V scale. Switch the range switch to 3V and adjust the potentiometer for exactly 1V. Move the probe to terminal 14. Read the meter and record the voltage across the capacitor in the ac column of Fig. 23-7. Compute the peak-to-peak value by multiplying the meter reading by 2.8. Record this in the peak-to-peak column.

Next, measure the ac voltage across the resistor. Unplug the power cord and clip the ground lead of the tvom to terminal 8. Plug the power cord in and touch the probe to terminal 14. Read the ac voltage across the 18K-ohm resistor. Record the reading in the space provided in Fig. 23-7. Compute the peak-to-peak value of the ac voltage across the resistor. Put the value also in Fig. 23-7. Unplug the power cord and disconnect your meter leads. Also unsolder the positive battery lead from terminal 8.

Discussion: The voltage you measured across the series resistor in Step 1 depends on the quality of the dielectric and the amount of leakage along the outside of the capacitor case. You probably will not measure any voltage drop across the resistor. If you had more sensitive measuring equipment and the dc voltage had been considerably higher, you would have measured a voltage drop across the resistor as the result of a dc flow through the dielectric of the capacitor, because no dielectric is a perfect insulator.

Of course, if we exceed the voltage rating of a dielectric, it will break down, and we no longer have a capacitor. A capacitor having a solid dielectric will block the flow of dc only if the applied voltage is kept below the rated working voltage of the capacitor.

In practical radio and TV circuits we also have to consider the effects of leakage along the outside of a capacitor. Moisture, dirt, and grease form conductive paths and decrease the effectiveness of the capacitor. It is essential, therefore, to keep equipment clean and dry.

In Step 2 you obtained some valuable experience using your tvom. Notice we first set the instrument on the 12-volt range, adjusted the potentiometer to less than 3 volts, and then switched to the 3-volt range. When you measure an unknown voltage, you should always begin by turning the range switch to one of the higher ranges. Then, when you are sure it is safe to do so, switch to a lower range to get more accurate readings.

The voltage you measured across the resistor in Step 3 with ac applied to the test circuit is clear evidence that a capacitor with a solid dielectric will pass ac. As we pointed out in your regular lesson on capacitors, the electrons do not actually pass through the dielectric of a capacitor; instead, they move to and from the capacitor plates, thus permitting a back and forth or ac flow in the circuit connected to the capacitor. As far as the rest of the circuit is concerned, the effect of this back and forth movement is the same as if the current actually passed through the dielectric of a capacitor.

You can consider that the readings you obtain in Steps 1, 2 and 3 are correct if you find that the voltage across the resistor is greater when ac is applied to the circuit than when dc is applied.

In Step 4 you worked with a circuit having both ac and dc voltages applied to the capacitor. The nearly 0 volt dc reading across the 18K-ohm resistor shows that the electrolytic capacitor blocks the dc current. This is to be expected because the dc voltage is applied with the correct polarity to the plates of the capacitor. The 3-volt dc reading across the capacitor shows that in this circuit the battery potential appears across the plates of the capacitor. When the ac voltage is applied to the circuit, the capacitor couples the ac voltage through the capacitor and almost the entire applied ac voltage appears across the 18K-ohm resistor. The large 20-mfd electrolytic capacitor offers almost no opposition to the flow of alternating current at a frequency of 60 Hertz. Therefore, the ac voltage reading across the capacitor is nearly zero. You will often find electrolytic capacitors used as coupling capacitors in transistor circuits. The value of these electrolytic coupling capacitors is frequently 5 mfd or greater.

At low audio frequencies, a sizable ac voltage develops across a capacitor of this size. You will find that the capacitors are connected in the circuit in such a way that a dc bias potential is placed on the capacitor. The dc potential has the correct polarity to prevent the voltage on the capacitor plates from reversing when an ac signal is applied to it.

Instructions for Statement No. 23: For the Statement in this experiment, you are to determine the opposition offered by your .25-mfd capacitor to the flow of 60 Hertz ac.

When we speak of opposition to ac, we actually mean impedance. However, if the ac resistance of the capacitor is very low, as it is in a capacitor with a good solid dielectric, the impedance is practically the same as the reactance of the capacitor. Therefore, although you will really determine the impedance of your capacitor for 60 Hertz ac in this experiment, you can consider your result to be its reactance at that frequency also.

To get the information you need to calculate the impedance of the capacitor, disconnect and remove the 20-mfd capacitor and the 18K-ohm resistor. Solder one lead of a 1K-ohm resistor to terminal 17 of the 1K-ohm potentiometer. Connect the other lead to terminal 14. Solder a .25-mfd capacitor from terminal 14 to terminal 5. See Fig. 23-8.

Connect the ground clip of your tvom to terminal 14 and plug the power cord into an ac receptacle. With your tvom on the 3-volt ac range, touch the probe to terminal 17, and adjust the potentiometer to give you a voltage of less than 1.2V across the 1K-ohm resistor. Switch to the 1.2V range and adjust for .5V. The current in the circuit will now be .5 milliampere or .0005 ampere.

Turn the range switch on your tvom to the 12V position, and touch the probe to the chassis. The reading on your tvom is the voltage across the capacitor with an alternating current of .0005 ampere flowing through it. Remember to read your tvom on the 12V scale when you measure this voltage.

To determine the impedance of the capacitor, all you need do is apply Ohm's Law. Divide the voltage that you mea-

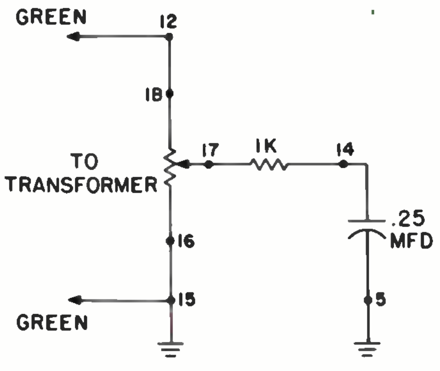


Fig. 23-8. Circuit used for Statement 23.

$\frac{5.2V}{.5ma}$

$.5ma \overline{)5.2}$ 10.4K
-5
2
-2
20
-20

$X_c = \frac{1}{2\pi F C}$

sured across the capacitor by the current (.0005 ampere), and you will have the impedance. Perform this computation and answer the Statement. Disconnect your power cord from the power line. Do not disconnect the 1K-ohm resistor and the .25-mfd capacitor. You will use them in the following experiment.

Statement No. 23: I found that the impedance of my .25-mfd capacitor was:

(1) approximately 3,000 ohms.
[✓ *(2) approximately 10,000 ohms.*]
(3) approximately 30,000 ohms.

EXPERIMENT 24

Purpose: To show that when capacitors are connected in parallel, their combined capacitance is equal to the sum of their individual capacitances; and to show that when capacitors are connected in series, their combined capacitance is less than that of the smallest capacitor.

Introductory Discussion: The capacitance of a capacitor depends upon four things: (1) the area of the plates, (2) the number of plates, (3) the distance between adjacent plates, and (4) the kind of dielectric or plate separator material used. If any one or any combination of these four things is varied, the capacitance changes.

As you have learned in your lessons, when capacitors are connected in parallel, the plate area is effectively increased. Therefore, the capacitance should increase. In this experiment, you will show that the capacitance increases, and that it is equal to the sum of the capacitance of the individual capacitors.

Capacitors can also be connected in series. As you learned in your lessons, connecting capacitors in series is electrically equivalent to increasing the thickness of the dielectric material between the plates. This should decrease the capacitance. You will show that this is actually what does take place.

To show exactly how much the capacitance changes, you will use the same procedure you used in the Statement of the preceding experiment to determine the impedance of the combination of capacitors.

The capacitance of a capacitor can be calculated by rearranging the formula for capacitive reactance, if you know the reactance and the frequency. For all practical purposes, the reactance of the capacitor at that frequency is equal to its impedance. Thus, since we know the impedance we can find the capacitance by using the formula

$$X_C = \frac{1}{6.28fC}$$

If we rearrange this formula, we can write it in the form

$$C = \frac{1}{6.28fX_C}$$

By substituting the impedance value you determine for X_C and 60 for f, you can get the capacitance in farads. You can convert this to microfarads by multiplying by 1,000,000.

As a serviceman, you will not have to make this type of calculation. Therefore, we have prepared a graph that you can use to determine the capacitance once you have the impedance. The graph is a plot of reactance in ohms at 60 Hertz plotted against capacitance in mfd. If you know the value of the capacitor, you can find its reactance in ohms at 60 Hertz. Or if you know the reactance in ohms at 60 Hertz, you can find the capacitance in mfds. You get the same information from the graph that you would get by working out the reactance formula.

The important thing for you to watch in this experiment is what happens to the total capacity when you put capacitors in parallel or in series.

Your first set of measurements will be made with two capacitors connected in parallel. The capacitance you compute should be nearly equal to the sum of the rated capacitances. Because of manufacturing tolerances, the actual capacitance will probably not be the same as the rated capacitance, so the calculated capacitance will probably be somewhat different from the sum of the rated values.

After making measurements and computations for capacitors connected in parallel, you will connect the same two capacitors in series and repeat the measurements. This time you should find that your computed capacitance is less that that of the rated value of the smallest capacitor in the combination.

Experimental Procedure: For this experiment, you need the circuit from the preceding experiment and:

1 10K-ohm resistor
1 .1-mfd capacitor (CN12)
1 .25-mfd capacitor

From now on, we will not give you step-by-step instructions for using your tvom in making all the measurements required in your experiments. We will occasionally tell you how to connect the test leads, but for the most part we will merely tell you to make the measurements and leave it up to you to set up the tvom properly from them. Of course, we will give you help when you use the instrument on a range that you have not used before in the experiments.

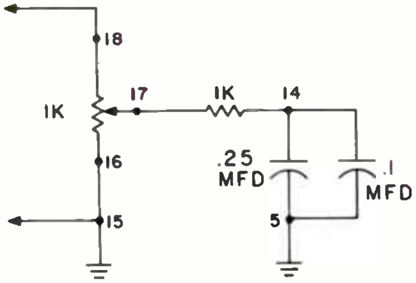


Fig. 24-1. Schematic showing capacitors in parallel across the potentiometer.

To connect the capacitors in parallel, set up the circuit shown in the schematic diagram in Fig. 24-1 and the pictorial diagram in Fig. 24-2. Since you already have the 1K-ohm resistor and the .25-mfd capacitor in place, all you need to do is connect the .1-mfd capacitor in parallel with the .25-mfd capacitor from terminal 5 to terminal 14.

Step 1. To adjust the voltage across the resistor to a fixed value.

Connect the tvom across the 1K-ohm resistor and set the range switch to 12V. Apply ac power to the voltage divider, and adjust the potentiometer to produce a meter reading of less than 1 volt on the 12V scale. Now switch to the 1.2-volt range and adjust the potentiometer to give you a voltage of .5 volt across the

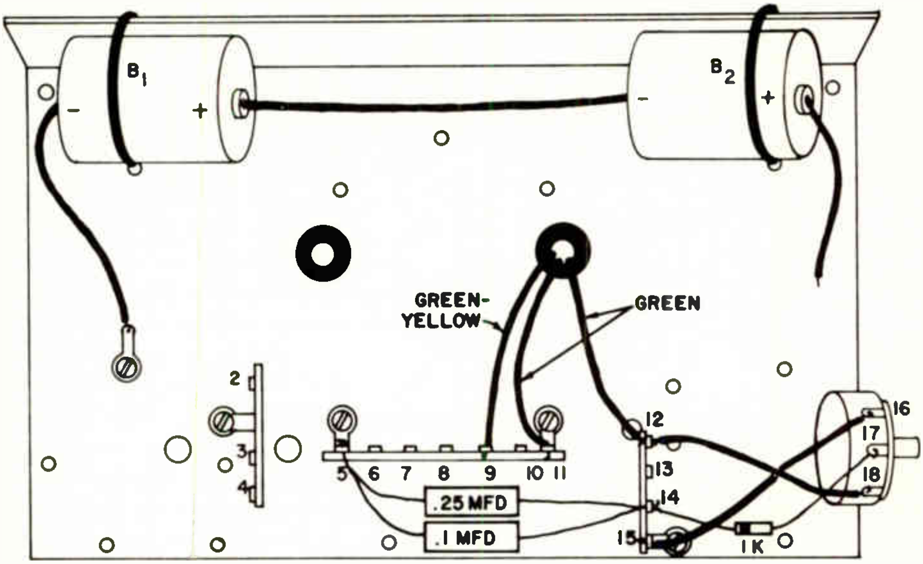


Fig. 24-2. Chassis layout for Step 1.

1K-ohm resistor. You now have a current of .5 milliampere flowing in the circuit. Adjust this voltage as accurately as you can. A small error here will cause a considerable error in your computed capacitance value. Unplug the power cord.

Step 2. To measure the ac voltage drop across the capacitors.

Switch the tvom to the 12V range and connect it across the parallel-connected capacitors. Plug the power cord into the ac outlet. Record the measured voltage in Fig. 24-3. Unplug the power cord.

Step 3. To determine the impedance of the parallel-connected capacitors.

You know the current in the circuit is .5 milliampere. To calculate the impedance, divide this current value into the voltage value you measured across the capacitors. An easy way to do this is to multiply the voltage by 10,000 and then simply divide by 5.

When we carried out this experiment in the laboratory, we had a voltage of 3.5 volts across the combination. Multiplying this by 10,000 gave us 35,000, and dividing this by 5 we got 7000 ohms as

CAPACITOR GROUPING	VOLTAGE ACROSS CAPACITORS	CURRENT IN AMPS	REACTANCE IN OHMS	CAPACITANCE IN MFD
PARALLEL	3.6V	.0005	7.2K	.35
SERIES	4V	.0001	40K	

Fig. 24-3. Results of Experiment 24.

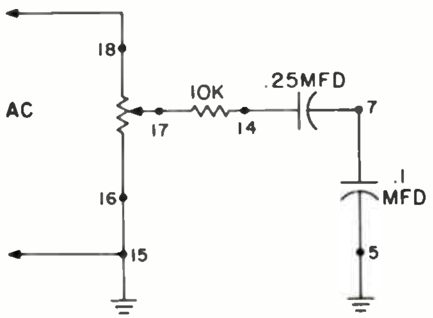


Fig. 24-4. The capacitors are connected in series.

the impedance of the combination. Your value should be reasonably close to this figure. Record the impedance you calculated in Fig. 24-3 in the column headed "Reactance in Ohms."

Connect the capacitors in series, as shown in Fig. 24-4. Unsolder the lead of the .1-mfd capacitor from terminal 14 and connect it to terminal 7. Unsolder the lead of the .25-mfd capacitor from terminal 5 and solder it to terminal 7. Unsolder and remove the 1K-ohm resistor and replace it with the 10K-ohm resistor from terminal 14 to terminal 17 of the potentiometer.

Step 4. To adjust the voltage across the resistor to 1 volt, and measure the voltage across the series-connected capacitors.

Connect the tvom across the 10K-ohm resistor. With the range switch in the 12-volt position, energize your circuit and adjust the potentiometer to give you a voltage less than 3 volts. Then switch to the 3V range, and adjust the potentiometer to give you a voltage of 1 volt.

Unplug the power cord to the voltage divider, switch the range switch to the 12V position, and connect the tvom across the two capacitors connected in series from the chassis to terminal 14. Plug in the power cord to the voltage divider and read the meter. Be sure to switch to the 3V range if the voltage is less than about 2.5 volts. Record your reading in Fig. 24-3. Disconnect the ac power.

Step 5. To determine the impedance of the series-connected capacitors.

You can easily determine the value of the current in the circuit. Since you have one volt across a 10K-ohm resistor, the current must be 1 ÷ 10,000, which is .0001 ampere. To determine the impedance, you must divide the voltage across the two capacitors by this current. Again, an easy way to do this is to multiply the voltage by 10,000. Do this and enter your value in Fig. 24-3.

Step 6. To find the net capacitance of the two capacitors connected in parallel.

Use the graph shown in Fig. 24-5. Notice the dark vertical lines. Each one of these lines represents 5000 ohms. The lines representing 30,000 and 60,000 ohms are marked. In the example we gave, where we had an impedance of 7000 ohms, we would find the vertical line representing 7000 ohms. This is the seventh line from the left. The first dark line to the right of the zero line is 5000 ohms; the second light line to the right of the 5000-ohm line is the 7000-ohm line. Now follow this line up until it crosses the curve on the graph, and then follow the nearest horizontal line to the left side of the graph.

In our example, the vertical 7000-ohm

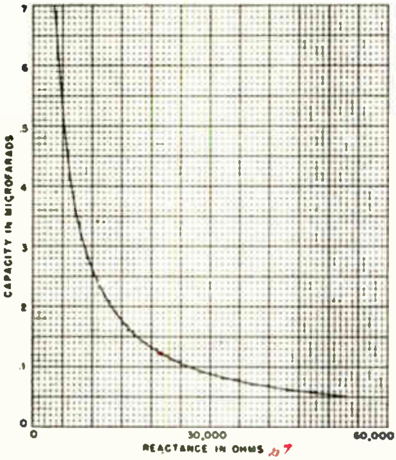


Fig. 24-5. Graphic plot of reactance in ohms at 60 cycles plotted against capacitance in mfd. You will use this graph in Steps 6 and 7.

line intersects the curve about 2 lines above the dark horizontal line, midway between .3 and .4. This dark line represents .35 mfd, and since there are five lines between it and .4 mfd, the second line above .35 represents .37-mfd. This means the parallel capacitance is .37-mfd, which is close to the value we obtain by adding .25-mfd and .1-mfd. Now, determine the capacitance of your parallel combination using Fig. 24-5.

Step 7. To determine the net capacitance of the capacitors when they are connected in series.

Use the value of reactance in ohms that you obtained in Step 5 when the capacitors were connected in series. Enter this value of reactance in the graph in Fig. 24-5 and find the value of capacitance. You should find that the total capacitance of the two in series is about .07-mfd.

Discussion: The actual value of your capacitors may be quite different from the capacitance marked on them. Most capacitors of this type have tolerances of +20% and -10%. Thus, the actual capacitance of your .25-mfd capacitor may be anything between .225-mfd and .3-mfd, and the actual capacitance of your .1-mfd capacitor may be any value between .09 and .12 mfd. Therefore, the sum of their actual capacitance may be anywhere from .32-mfd to .42-mfd, even though the sum of their rated capacitance is .35-mfd. However, as far as any of the experiments in your practical training course are concerned, you can find the capacitance of a group of capacitors accurately enough for all practical purposes by using the rated capacitance of the individual capacitors in your computations.

This experiment has proved that the capacitance of a group of capacitors connected in parallel is larger than that of any of the individual capacitors, and that the capacitance of a group connected in series is less than that of the smallest of the group. We can find the capacitance of a group of capacitors connected in parallel by adding the value of the individual capacitors. To find the capacitance of two capacitors connected in series, you can use the formula:

$$C = \frac{C_1 \times C_2}{C_1 + C_2}$$

If there are more than two in the series group, work with just two at a time, and find the net capacitance by applying the formula as many times as necessary.

Instructions for Statement No. 24: Remove the .1-mfd capacitor from the circuit and connect a .25-mfd capacitor in its place between terminals 5 and 7. You should now have two .25-mfd capacitors in series with the ac voltage source and the 10K-ohm resistor. Connect your tvom across the 10K-ohm resistor, and apply power to the voltage divider. Adjust the potentiometer for a voltage of 1 volt across the 10K-ohm resistor. Next, measure the voltage across the two .25-mfd capacitors in series. Unplug the power cord, compute the impedance, and then determine the net capacitance of the combination from the graph in Fig. 24-5. Use exactly the same procedure you followed in the experiment.

Compare the net capacitance you have computed with the capacitance of one of the two capacitors. Then, choose the answer in the Statement below and on the Report Sheet that most nearly represents the results of your comparison.

When you have done this, disconnect the 10K-ohm resistor and put it aside. Do not remove the two .25-mfd capacitors from the circuit, however. They will be used in the following experiment.

Statement No. 24: When I connected two capacitors of equal capacitance in series, the net capacitance was approximately: .12 mfd.

[✓ *(1) one-half*]
(2) four times
(3) the same as
(4) twice

that of one capacitor alone.

EXPERIMENT 25

Purpose: To show that when ac is applied to two or more capacitors connected in series, the sum of the voltage drops across the capacitors equals the source voltage; and

To show that the capacitor with the lowest capacitance will have the most voltage across it.

Introductory Discussion: In this experiment, you will show that voltage applied to several series-connected capacitors divides among them in accordance with their individual reactances. You will do so by connecting three capacitors in series, and measuring the ac voltage drop across each. You will remember that you performed a similar experiment to show that in a dc circuit the sum of the voltage drops is equal to the source voltage. This is Kirchhoff's Voltage Law. You have seen that it works for dc; you will now prove that it is also true in ac circuits.

Experimental Procedure: In addition to your chassis and tvom, the parts you need for this experiment are:

1 .1-mfd capacitor
1 47K-ohm resistor
1 18K-ohm resistor

Set up the circuit shown in Fig. 25-1 as follows:

You should have two .25-mfd capaci-

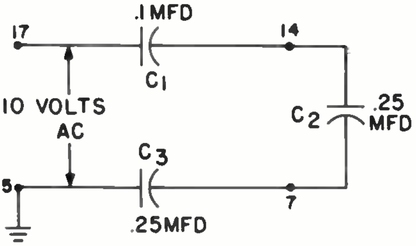


Fig. 25-1. Schematic of the circuit for Exp. 25.

$\frac{2.2V}{.0001A} = 22K\Omega$

tors connected in series, one from terminal 5 to terminal 7 and the other from terminal 7 to terminal 14. Connect one lead of a .1-mfd capacitor to terminal 14. Solder the connection. Solder the other lead of the .1-mfd capacitor to terminal 17 of the potentiometer. The chassis should now appear as shown in Fig. 25-2.

Now connect the ground clip of the tvom to the chassis. Touch the probe to terminal 17 of the potentiometer. Switch your tvom to the 12V range, apply power to the circuit, and adjust the voltage until the meter indicates exactly 10 volts.

Step 1. To measure the ac voltage across one of the .25-mfd capacitors.

You already have the ground lead of your tvom connected to the chassis ground. To measure the voltage across capacitor C_3, touch the meter probe to terminal 7. Record your reading on the first line in Fig. 25-3.

Step 2. To measure the ac voltage across the second .25-mfd capacitor.

Remove the power cord. You must do this, because it is not good practice to change the connections of the tvom while the circuit is energized. The safest procedure, both for yourself and for the tvom, is to unplug the power cord of the circuit you are working on before changing the connections of the tvom test leads. Do not plug the power cord in again until you have the tvom connected for the next measurement.

Transfer the ground clip of the tvom to terminal 7, which is the junction point of the two .25-mfd capacitors. Apply the ac power, and touch the tvom probe to terminal 14. Read the meter carefully,

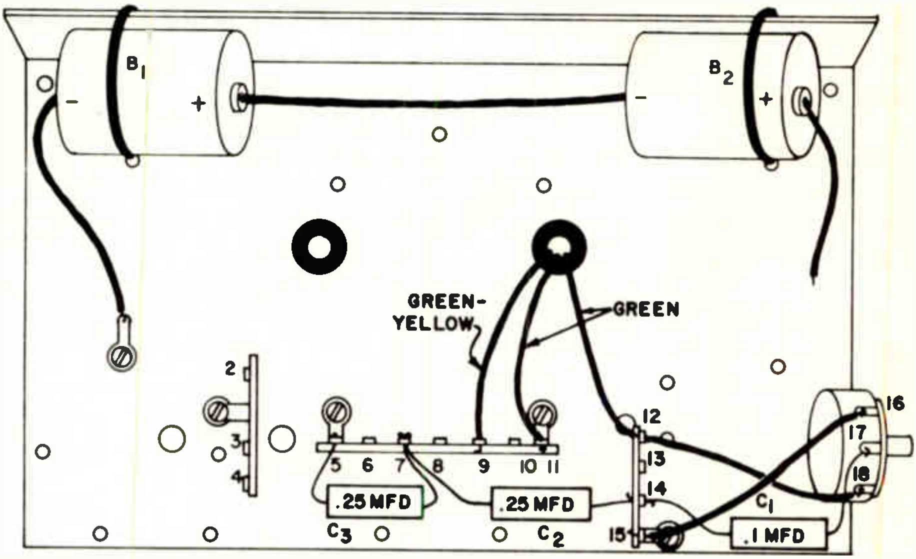


Fig. 25-2. The wiring for Step 1.

	YOUR READING
STEP 1	2.2V
STEP 2	2.15V
STEP 3	5.4V
TOTAL	9.75V

Fig. 25-3. Results of Experiment 25.

and record your reading on the second line in Fig. 25-3.

Step 3. To measure the voltage across the .1-mfd capacitor.

Unplug the power cord from the ac source, and move the ground clip to the junction of the .1-mfd capacitor and the .25-mfd capacitor at terminal 14. Then, reapply the power, touch the probe to terminal 17 of the potentiometer, and read the meter carefully. Record your voltage measurement on line 3 of Fig. 25-3.

Unplug the circuit and unsolder and remove all three capacitors from the circuit. Keep them handy for use in the Statement of this experiment.

Discussion: The voltages you recorded in the table in Fig. 25-3 should show you two things. First, the sum of the individual drops should be approximately equal to the source voltage. Add the voltages you measured in Steps 1, 2 and 3, and record the total in the space provided in Fig. 25-3. Since it is difficult to read small voltages accurately, the sum of your voltage may not be exactly 10 volts. You should, however, come close enough to be able to say that the sum of the voltage drops equals the source voltage within the limits of accuracy of your experimental measurements.

From the readings, you should also notice that the greatest voltage drop is across the smallest capacitance. Since it is the smallest capacitance that has the highest reactance at any given frequency, your measurements prove that the greatest voltage drop is across the highest reactance. The voltage drops across the two .25-mfd capacitors should be approximately equal. If you were to compute the reactance of each capacitor, you would see that the voltage drops were proportional to the individual reactances.

If you want to do this, find the reactance by using the formula

$$X_C = \frac{159{,}000}{fC}$$

in which f is the frequency in Hertz of the applied voltage and C is the capacitance in microfarads.

For example, to find the reactance of the .1-mfd capacitor, multiply 60 (the power-supply frequency) by .1. This answer is 6. Dividing this into 159,000, you get the value 26,500, which is the reactance in ohms of the capacitor at 60 Hertz. You can compute the reactance of the .25-mfd capacitors in exactly the same way.

Instructions for Statement No. 25: For your report on this experiment, you are going to determine what happens when a coupling capacitor has leakage.

A very common radio and TV circuit uses a capacitor to pass the ac signal from the plate circuit of one stage to the grid circuit of the next stage. We can simulate

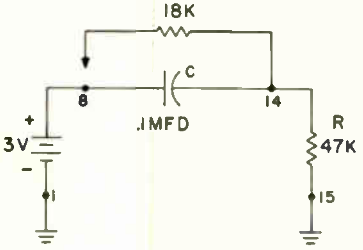


Fig. 25-4. Circuit used for Statement 25.

such a circuit as shown in Fig. 25-4. The 3-volt battery represents the plate supply, capacitor C acts as the coupling capacitor, and resistor R represents the grid resistor of the next stage. We know that ac passes through the capacitor, but should there be a dc voltage across R? Will there be if C is leaking? To find out, we will use the 18K-ohm resistor to simulate leakage in the capacitor. Wire the circuit shown in Fig. 25-4. Notice that one lead of the 18K-ohm resistor is not connected as yet.

Use your tvom as a dc voltmeter and measure the dc voltage across the 47K-ohm resistor. Make a note of your reading in the margin of this page.

0V

Next, simulate leakage in the .1-mfd capacitor by connecting the 18K-ohm resistor in parallel with it. To do this, solder the free lead of this resistor to terminal 8. Again measure the dc voltage across the 47K-ohm resistor R. Make a note of your reading in the margin.

1.6V

Unsolder and remove the capacitor and the two resistors. Leave the battery and the ac voltage divider. Complete the Statement below and on the Report Sheet.

Statement No. 25: When I simulated leakage by connecting the 18K-ohm resistor across the capacitor, I found that the dc voltage across resistor R was:

(1) the same as
[✓ *(2) greater than*]
(3) less than

it was before the leakage resistor was connected.

Using Vectors To Combine AC Quantities

In a circuit in which the resistance is the only device that opposes the flow of alternating current, the voltage drop across each resistor is in phase with the current. By this we mean that during each cycle, the voltage and current maximums and minimums occur at the same instant.

In other words, at the instant when the ac voltage is zero, the current also is zero; and at the instant the voltage is at its peak value, the current is at its peak value. Consequently, the sum of the individual voltage drops in the circuit is equal to the source voltage.

When the circuit contains reactance as well as resistance, however, the resulting phase shifts make it impossible to simply add the voltage drops, because the voltages do not reach their peaks at the same time. Complex mathematics can be used to combine ac values, but there is a much simpler graphical method. This is in the use of vectors. Vectors are important because they help you see exactly what is happening in an ac circuit. You will also use them later, particularly when you study color television.

A vector is a line whose length is proportional to the magnitude of a voltage or current, and whose position with respect to other vectors or to a reference position indicates phase relationship. In other words, both the length of the vector and its position convey information.

Fig. 9. A simple vector.

A simple vector is shown in Fig. 9. If the line OA is a voltage vector, the length of the line indicates an amount of voltage. For example, if a scale in which 1 inch equals 1 volt is being used, a line 5 inches long would represent a voltage of 5 volts. If line OA is a current vector, its length represents an amount of current, depending on the scale used.

The reference or starting position for vectors is along a line drawn to the right of the point of origin, O.

A vector is considered to rotate in a counterclockwise direction only. If it forms an angle with the reference vector and is pointing upward, it is considered to be ahead of, or leading, the reference vector. If it is pointing downward, it is considered to be lagging behind the reference vector.

For example, in Fig. 10, vector OB is said to be 90° ahead of OA, and vector OC is said to be 90° behind OA. A complete cycle is 360°. Therefore, we

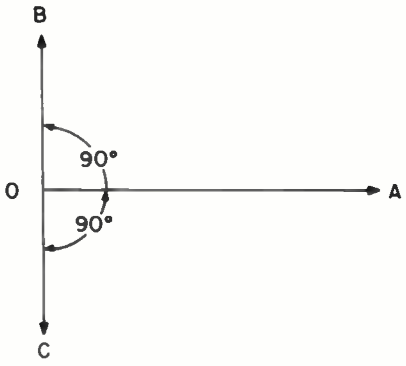


Fig. 10. Vectors show magnitude and phase.

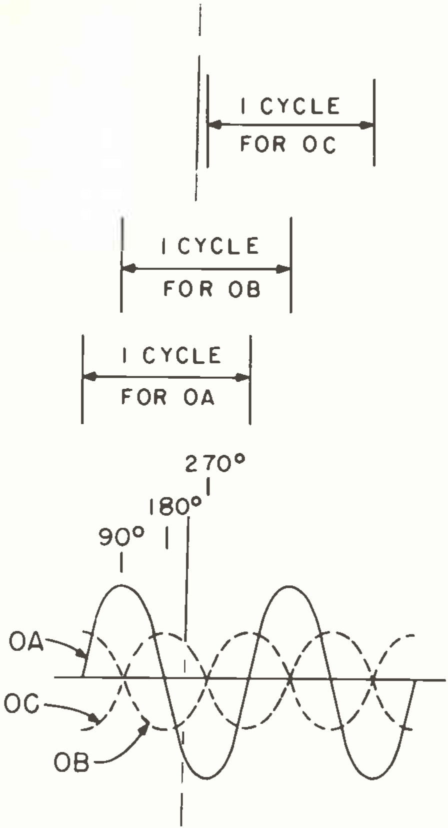


Fig. 11. Another way of showing Fig. 10 values.

could consider OC to be 270° ahead of OA; but if one cycle of OC is 270° ahead of one cycle of OA, that same cycle is 90° behind the next cycle of OA. Thus, it is customary to say that OC lags behind OA by 90° rather than leads it by 270°. This is illustrated in Fig. 11, in which each voltage is represented by a sine wave.

When two or more voltages or currents are to be compared, one vector is drawn for each. One is usually placed in the reference position and the others are drawn at an angle from the same point of origin. This angle represents the phase difference between the vectors. For example, vectors OA and OB, shown in Fig. 12A, represent two voltages. The voltage represented by OA is twice as great as the one represented by OB, and they are 90° out-of-phase. The phase difference between them is represented by the angle θ (the Greek letter theta is used to indicate a phase angle). Since the direction of rotation of vectors is always counterclockwise, we know vector OB leads vector OA by 90°. When voltage OB is one-quarter of the way through its cycle, OA is starting its cycle. The phase of two voltages or currents can be compared vectorially only if they have the same frequency so that one cycle of each frequency takes the same length of time.

The vector sum of the two voltages can be found by drawing the parallelogram shown in Fig. 12B. (A parallelogram is a four-sided figure, the opposite sides of which are parallel. Squares and rectangles are parallelograms in which all of the angles are 90°, or right angles.) To form this parallelogram, line BC is drawn parallel to vector OA, and line AC is drawn parallel to vector OB. Vector OC, the diagonal from point O to the point where the broken lines intersect, is the vector sum or "resultant" of the two voltages.

The angle between vectors OA and OB does not have to be a right angle (90°). For example, Fig. 12C shows two voltages that are considerably less than 90° out-of-phase. Whatever the angle may be, the vector sum can be found in the same way. Construct a parallelogram by drawing a line BC parallel to vector OA, and a line AC parallel to OB. The diagonal OC is the resultant.

If you compare the length of OC in Fig. 12C with the length of OC in Fig. 12B, you will find that they are different, even though the lengths of OB and OA are the same in both figures. This is

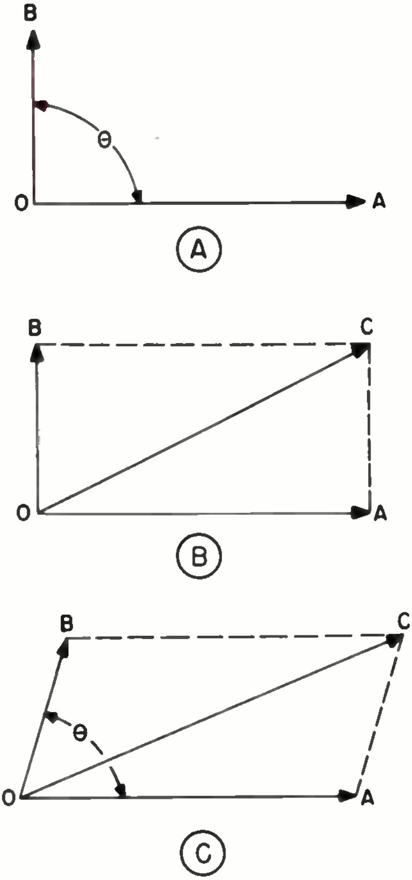


Fig. 12. How vectors are combined.

because the phase angle (θ) or relationship is not the same in both cases. Therefore, as you can see, the vector addition takes both amplitude and phase into account.

There is a form of vector shorthand that you should know about. It is illustrated in Fig. 13. A, C, and E show the standard method of completing the parallelograms. However, since the length of line AC is exactly that of line OB, there is really no need to draw OB -- we can draw AC instead, and thus find the resultant without having to construct the entire parallelogram.

B, D, and F of Fig. 13 show this short-cut method of finding the resultant. As you can see, all you need to do is to draw AC the same length and at the same angle that OB would be if it were drawn, and then draw in OC.

Whether you use the standard or the short-cut method of vector addition, you must make sure that the length of each vector corresponds to the amplitude of the voltage or current it represents, and that the phase angle is correct.

This brief explanation by no means covers the subject fully, but it covers the basic facts you need to know about vectors to work with the fundamental ac circuits used in the following experiments.

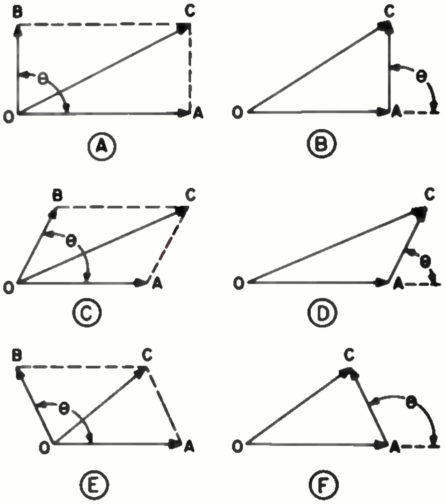


Fig. 13. A comparison between the "shorthand" method of adding two vectors by completing a triangle, and the conventional method of adding by completing a parallelogram. The result is the same in both cases.

EXPERIMENT 26

Purpose: To show that in an ac circuit containing only resistance, the sum of the individual voltage drops equals the source voltage with the greatest voltage being across the highest resistance; and

To show that in an ac circuit containing a capacitor and a resistor in series, the vector sum of the individual voltage drops equals the source voltage.

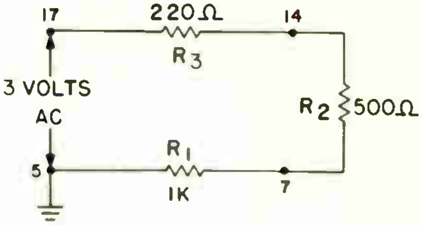


Fig. 26-1. Schematic of circuit for Steps 1,2,3.

Introductory Discussion: In carrying out the following experiment, you will first set up a circuit with three resistors connected in series, apply a specified ac voltage across the series circuit, and measure the ac voltage drop across each of the resistors. The sum of the individual voltage drops should equal the source voltage, because the voltages across the resistors are all in phase with each other.

Next, you will build a circuit with a capacitor in series with a resistor, apply an ac voltage across the combination, and measure the voltage drop across each component. The voltage drop across the capacitor lags behind the current through the capacitor by approximately 90°, but the current through the resistor is in phase with the capacitor current.

Therefore, the voltage across the capacitor is 90° out-of-phase with the voltage across the resistor. You will draw a vector

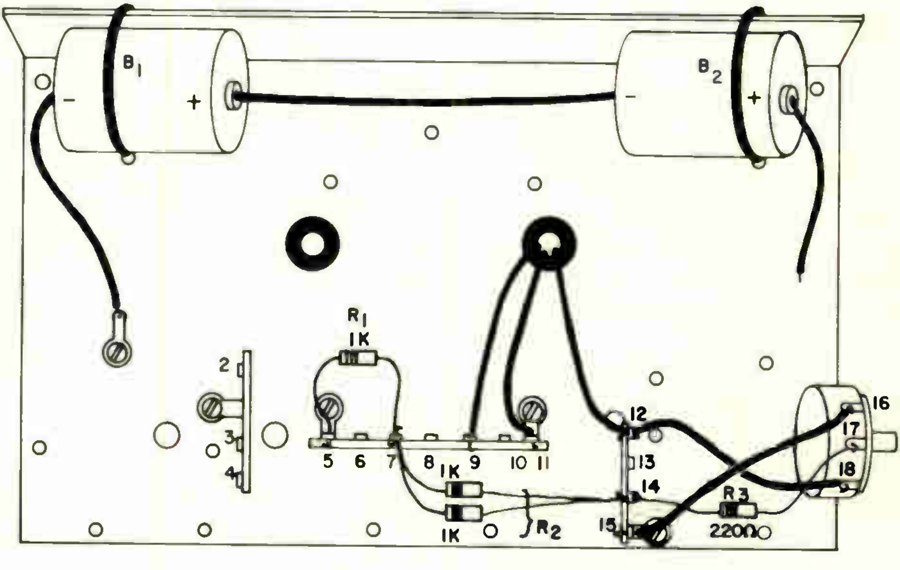


Fig. 26-2. Pictorial of circuit in Fig. 26-1.

diagram to show that the sum of the resistor voltage and the capacitor voltage is equal to the source voltage when the phase difference is taken into account.

Experimental Procedure: For this experiment, you need your experimental chassis, tvom and the following:

3 1K-ohm resistors
1 220-ohm resistor
1 18K-ohm resistor
1 .1-mfd capacitor
2 .25-mfd capacitors

You are to set up the simple series circuit shown in Fig. 26-1 across the ac voltage divider. A pictorial diagram is shown in Fig. 26-2.

Connect a 1K-ohm resistor from terminal 5 to terminal 7. Solder terminal 5. Now connect two 1000-ohm resistors in parallel from terminal 7 to terminal 14. Solder terminal 7. Connect the 220-ohm resistor from terminal 14 to terminal 17 on the potentiometer. Solder both terminals.

Connect the tvom ground clip to the chassis, plug in the power cord, touch the probe to terminal 17 and adjust the potentiometer to produce a voltage of exactly 3 volts ac. Remember to make an approximate adjustment on the 12V range first, and then switch to the 3V range.

Step 1. To measure the ac voltage drop across the 1K-ohm resistor R_1.

Leave the ground lead of the tvom clipped to the chassis and touch the probe to terminal 7. Read the meter carefully, then enter your reading on the first line of Fig. 26-3.

STEP	MEASUREMENT	YOUR VALUE
1	VOLTAGE ACROSS 1K	1.75
2	VOLTAGE ACROSS 500Ω	.83
3	VOLTAGE ACROSS 220Ω	.36
	TOTAL	2.94

Fig. 26-3. Results of Experiment 26.

Step 2. To measure the ac voltage across the 500-ohm resistance R_2.

Transfer the ground lead of the tvom to terminal 7. Touch the probe to terminal 14. Read the voltage, and record your reading on line 2 of Fig. 26-3.

Step 3. To measure the voltage across the 220-ohm resistor R_3.

Move the tvom ground clip to terminal 14. Touch the probe to terminal 17 of the potentiometer. Read the voltage, and enter your reading on line 3 of Fig. 26-3.

Unplug the line cord and remove all of the resistors. Wire the circuit shown in Fig. 26-4. Connect the 18K-ohm resistor from terminal 17 of the potentiometer to terminal 14. Connect the .1-mfd capaci-

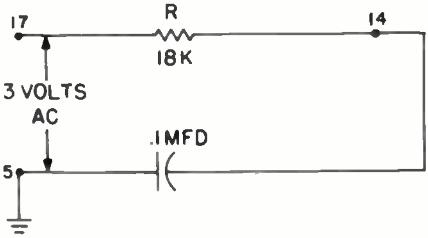


Fig. 26-4. Schematic diagram of the circuit used in Steps 4 and 5.

tor from terminal 14 to terminal 5. Solder all three connections.

Set your meter to the 12V range. Connect the ground clip of the tvom to the chassis, apply power to the voltage divider, and touch the probe to terminal 17. Adjust the potentiometer so that exactly 3 volts ac is applied to the test circuit.

Remember, the potentiometer that controls the supply voltage must be reset every time you change the parts used in an experimental setup. Each combination of parts draws a different current through the potentiometer and thus causes a different voltage drop across it, resulting in a different output from the voltage divider. Since we want to compare the results, we must set the divider voltage to the right value in each case. Also remember to switch your tvom to the 12V range when you start to adjust the potentiometer, and switch to a lower range only after you are sure it is safe to do so.

Step 4. To measure the ac voltage drop across the 18K-ohm resistor.

Connect the tvom negative lead to terminal 14. Touch the probe to the other lead of the resistor at terminal 17. Read the voltage and enter your reading in Fig. 26-5 as the voltage across the resistor for Step 4.

STEP NO.	NATURE OF MEASUREMENT	YOUR READING
4	VOLTAGE ACROSS 18K RESISTOR	1.6V
5	VOLTAGE ACROSS .1 MFD CAPACITOR	2.5V
	TOTAL	4.1V
	VECTOR TOTAL	2.968V

Fig. 26-5. Results of Steps 4 and 5.

Step 5. To measure the ac voltage across the .1-mfd capacitor.

Transfer the black test clip to the chassis. Touch the probe to terminal 14. Measure the voltage, and enter your reading in Fig. 26-5 as the voltage across the capacitor for Step 5. Unplug the power cord.

Discussion: The sum of the voltages you measured in Steps 1, 2 and 3 should be approximately equal to the source voltage. It will probably vary somewhat because of parts tolerances. However, add the voltages you have recorded for Steps 1, 2 and 3, and record your total in Fig. 26-3.

Next, add the voltages you measured in Steps 4 and 5, and record the sum on the line marked "Total" in Fig. 26-5. The sum of the voltages you measured across the capacitor and the resistor in Steps 4 and 5 should be greater than the source voltage, because the two voltage drops are not in phase. In fact, they are 90° out-of-phase. Therefore, we must add these voltages vectorially.

In drawing a vector diagram, we must have some starting point. In working with a series circuit, the current vector is used as a reference because current is common to all parts of a series circuit. The usual procedure is to draw the current vector first as a reference vector. In other words, the other vectors are drawn to show their relationship to the current vector. However, we have an 18K-ohm resistor in the circuit in Fig. 26-4, and the voltage across a resistor is always in phase with the current. Therefore, we can first draw the vector representing the voltage across the resistor and show the relationship of the other voltages to this vector.

As an example, let us suppose that we measured 1.75 volts across the resistor and 2.35 volts across the capacitor. We start the vector diagram by drawing a vector to represent the voltage across the 18K-ohm resistor. To do so, we draw a line OA as shown in Fig. 26-6, with the amount of voltage drawn according to some convenient scale. If we use a scale of 1 volt per inch to draw the vector, line OA will be 1-3/4 inches long.

Fig. 26-6. OA represents the voltage drop across the resistor.

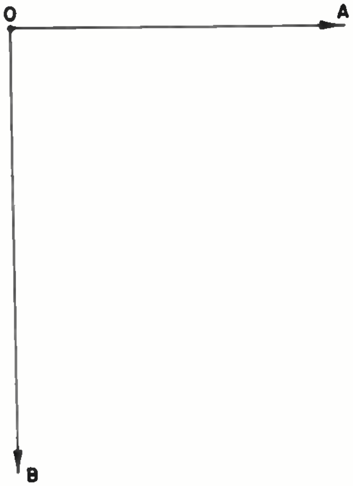


Fig. 26-7. OB represents the voltage drop across the capacitor.

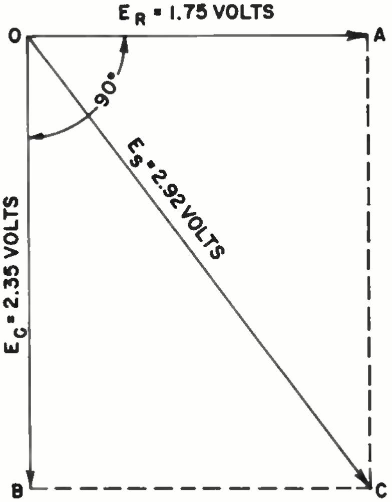


Fig. 26-8. Vector diagram of the sum of the voltage drops across the resistor and capacitor.

The voltage drop across the capacitor lags 90° behind the current, and hence lags 90° behind the resistor voltage drop also. Therefore, we draw the capacitor voltage vector straight downward from the origin O as line OB in Fig. 26-7, using the same scale to determine its length. If we measured 2.35 volts across the capacitor, this line will be a little over 2-5/16 inches long.

Now we complete the parallelogram by drawing line BC parallel to OA and line AC parallel to line OB. Next we draw the diagonal OC, as in Fig. 26-8, to represent the vector sum of the capacitor and resistor voltages. To find out how many volts OC represents, we measure its length and compare it with the voltage per-inch scale we used in drawing OA and OB. If you used a scale of one volt per inch, you should find that the length of OC is close to three inches.

The resultant could also be computed

mathematically by the process commonly used to solve right triangles. If you know how to solve this type of problem, using the Pythagorean Theorem, you can determine the vector sum in this way. If you are not familiar with this type of operation do not worry about it; use the graphical method.

Instructions for Statement No. 26: You have learned that the reactance of a capacitor decreases as its capacitance increases. If the capacitance is large enough, the current in a circuit can be almost as large as it would be if no capacitor were there.

We can, therefore, have a peculiar situation in a circuit that contains a large capacitor in series with the resistor. Even though the voltage drop across the capacitor may be appreciable, the fact that the voltage drops across the capacitor and the resistor are out-of-phase may mean that the voltage across the resistor is just about what it would be if the capacitor were out of the circuit.

To show this, connect the two .25-mfd capacitors in parallel with the .1-mfd capacitor as shown in Fig. 26-9. The total capacitance in the circuit is now .6-mfd.

Apply power to the voltage divider, and adjust the potentiometer until exactly 3 volts is applied between terminal 17 and the chassis. Measure the voltage drops across the 18K-ohm resistor and the .6-mfd capacity, and make notes of both. 7.4V 2.92

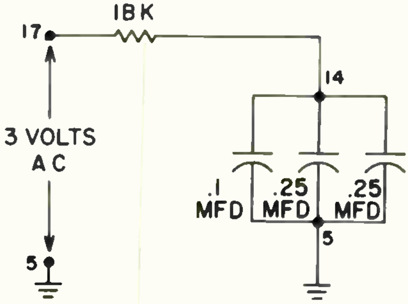


Fig. 26-9. Circuit for Statement 26.

Compare the resistor voltage you obtained in this Statement experiment with the one you found in Step 4. Bearing in mind that the voltage across the resistor is proportional to the current flowing in the circuit, determine what effect increasing the capacitance has had on the current. Finally, compare the voltage drop across the resistor with your source voltage of 3 volts. Complete the Statement below and on the Report Sheet.

Disconnect the power cord and turn off the tvom. Unsolder and remove the three capacitors and the resistor from the chassis, and lay them aside for future experiments.

Statement No. 26: When I used a capacity of .6-mfd instead of .1-mfd, I found that the current through the circuit:

[✓ *(1)*] *increased.*
(2) decreased.
(3) remained the same.

I found the resistor voltage to be:

(1) much higher than
(2) much lower than
[✓ *(3)*] *almost equal to*

the source voltage.

MOUNTING THE CHOKE COIL

Before going on to the next experiment, you must mount the choke coil on

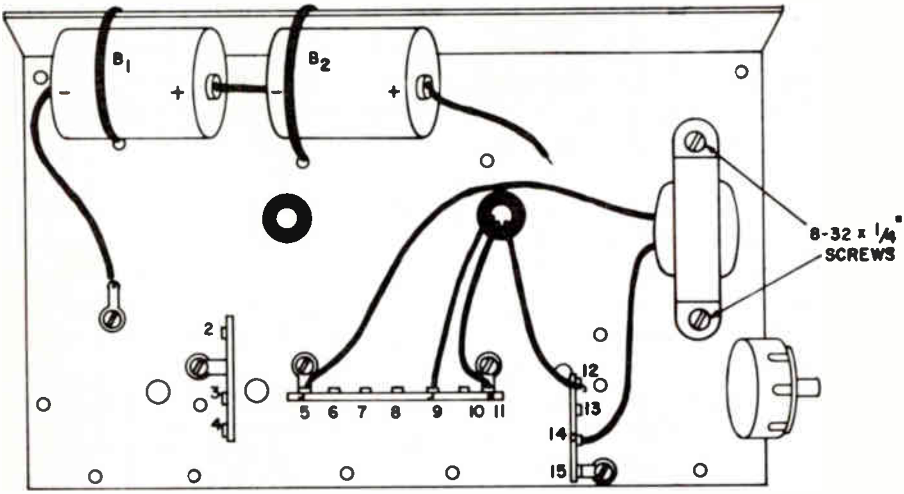


Fig. 14. The choke mounted on the experimental chassis.

the chassis. You will have to move one of the flashlight cells to make room.

You will need the following:

1 Choke coil (C026)
2 1/4" X 8-32 screws
2 8-32 hex nuts
2 No. 8 lockwashers

Move flashlight cell B_2 from the right side of your chassis to the left as shown in Fig. 14. Shorten the wire connecting the two cells together if you wish. To secure the cell to the chassis, you can run a length of hookup wire or string through hole F in the chassis between the unused rubber grommet and the bend in the chassis.

Position the choke on top of the chassis exactly as shown in Fig. 14. Pass 1/4" X 8-32 screws down through the holes in the mounting feet of the choke and through holes M and N in the chassis. Attach with No. 8 lockwashers and 8-32 hex nuts and tighten.

Connect and solder one choke lead to terminal 5. Connect and solder the other choke lead to terminal 14.

EXPERIMENT 27

Purpose: To show that the opposition offered by a coil to the flow of an alternating current is many times its opposition to the flow of a direct current.

Introductory Discussion: Coils are usually wound of copper wire, which, when stretched out, is practically as good a conductor for low frequency ac as it is for dc. Winding the wire in the form of a coil makes no change in its dc resistance, but it does cause a great increase in its inductance, thereby increasing its inductive reactance and its impedance. The opposition that the coil offers to ac, therefore, is much greater than its opposition to dc.

You have studied these properties in your lessons. We shall consider only the opposition of the coil to ac as compared to its opposition to dc in this experiment, but we suggest that you review these lessons to refresh your memory concerning the impedance, reactance, and inductance of coils and the application of Ohm's Law to them.

You will first determine the current through an iron-core choke coil when it is connected in series with a resistance of 1000 ohms to a 3-volt dc source. Next, you will apply 3 volts ac to the circuit, and determine the current. Finally, you will compare the two currents. Your results will show that the alternating current is much less than the direct current.

Experimental Procedure: You will need the experimental chassis, the tvom and the following:

2 1K-ohm resistors

Wire the circuit shown in Fig. 27-1.

The symbol **L** is used on schematic diagrams to represent a coil or an inductance. The parallel lines beside it indicate that the coil has an iron core.

Solder one lead of a 1K-ohm resistor to terminal 14. Connect the other resistor lead to terminal 13. Solder the free end of the positive battery lead to terminal 13.

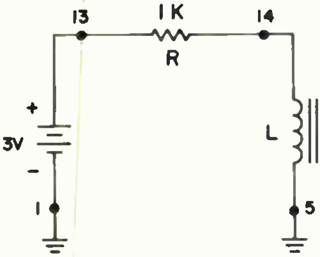


Fig. 27-1. Schematic for Step 1.

Step 1. To measure the dc voltage drop across the 1K-ohm resistor.

First, prepare your tvom for dc measurements on the 3V range. Fasten the ground clip to terminal 14 and touch the probe to terminal 13. Read the meter, and record your reading in Fig. 27-2.

STEP NO.	NATURE OF MEASUREMENT	YOUR VALUE IN VOLTS
1	DC VOLTS ACROSS R	1.75
3	AC VOLTS ACROSS R	.5V

Fig. 27-2. Results of Steps 1 and 3.

Since the resistance is 1000 ohms, the voltage across the resistor in volts will be equal to the current in milliamperes through the resistor. This was demonstrated in an earlier experiment.

Now, disconnect the test leads from the resistor, and unsolder the positive battery lead.

Step 2. To apply an ac voltage equivalent to the dc voltage used in Step 1 to the circuit.

Set up the circuit shown in Fig. 27-3. Unsolder the lead of the 1K-ohm resistor from terminal 13 and solder it to terminal 17 on the potentiometer. Switch the function switch in your tvom to ac. Connect the ground lead to the chassis, apply power to the voltage divider, touch the probe to terminal 17, and adjust the potentiometer to produce a voltage of exactly 3 volts.

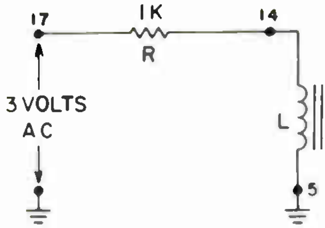


Fig. 27-3. Schematic of the circuit used in Step 2 and Step 3.

Step 3. To measure the ac voltage across the 1K-ohm resistor.

Move the ground clip to terminal 14, and touch the probe to terminal 17. Read the meter carefully on the 3V scale. Record your reading in Fig. 27-2, and unplug the voltage divider.

Discussion. The voltage you measured across the 1K-ohm resistor when a dc voltage was applied in Step 1 should have been considerably greater than the ac voltage drop you measured in Step 3, thus proving that the circuit current was less. Since the only difference between the circuits used for these two steps is the nature of the source voltage, we can say that the opposition offered by a coil is much greater for ac than for dc.

The opposition that your coil offers to alternating current is known as its impedance and is measured in ohms. There are several ways in which it can be determined. One quick method, which does not involve complex equipment and yet is reasonably accurate, is to connect the coil in series with a resistor, apply an ac voltage of known frequency, and measure the voltage drops across the resistor and the coil. Since the voltage drop across each part is proportional to the opposition offered by that part, we can set up the following equation:

$$\frac{E_L}{E_R} = \frac{Z}{R}$$

where E_L is the voltage across the coil, E_R is the voltage across the resistor, R is the resistance of the resistor, and Z is the impedance of the coil. This can be simplified by writing the equation in this form:

$$Z = \frac{E_L \times R}{E_R}$$

For your report on this experiment, you will find the approximate impedance of the coil by using this method. The impedance of the coil establishes the amount of current through the coil at the time of the measurement.

Instructions for Statement No. 27: Use the circuit shown in Fig. 27-3, but reduce the resistance of R to 500 ohms. This can be done by connecting another 1K-ohm resistor in parallel with the one now in series with the choke coil. When you have soldered the resistor in place, connect the tvom to the output of the voltage divider, and apply power. Adjust the potentiometer until a voltage of exactly 3 volts is applied to the coil and resistor.

Measure the ac voltage across the 500-ohm resistance; then measure the voltage across the coil. Use the 3V range for both measurements. Make a note of the readings you get, and unplug the ac power cord. .32V 2.734

To find the approximate impedance of your coil, use the formula

$$Z = \frac{E_L \times R}{E_R}$$

Multiply the voltage across the coil by 500 (the resistance of the resistor). Then divide the result by the voltage across the 500-ohm resistor. The result you get is the approximate impedance of the coil in ohms.

4.5K Ω Make a note of the value you obtained for the impedance of the coil, and then determine the dc resistance of the coil. You can use the ohmmeter section of your tvom to measure the dc resistance, but you must disconnect one lead of the coil in order to do this. Unsolder the choke coil lead from terminal 5, and connect the ground clip to one choke lead and the probe to the other lead. Reconnect the choke lead to terminal 5. Now, compare the impedance of the coil with the dc resistance, and answer the Statement.

300Ω

Statement No. 27: When I compared the dc resistance of the choke coil with its impedance, I found that the resistance was:

[✓ *(1) less than*]
(2) approximately equal to
(3) greater than

the impedance of the coil.

EXPERIMENT 28

Purpose: to show that the voltage drop across a coil is less than 90° out-of-phase with the current flowing through it because the coil has appreciable ac resistance; and

To show that we can find the phase angle by using vectors.

Introductory Discussion: In a previous experiment, you proved that the vector sum of the voltage across a capacitor and a resistor in series is equal to the source voltage, if the drop across the capacitor is considered to be 90° out-of-phase with the resistor voltage.

In any good solid-dielectric capacitor, the ac resistance is so small that it can be ignored. Therefore, we can say that the impedance of such a capacitor is equal to its reactance. Thus, the voltage across the capacitor is 90° out-of-phase with the current through it and 90° out-of-phase with the voltage across any resistor in series with it.

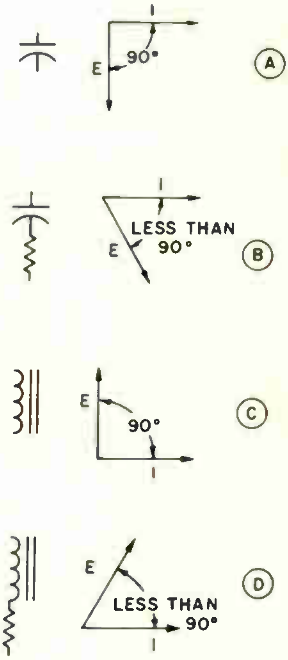


Fig. 28-1. The general phase relationship between the terminal voltage and the current when we have: (A) a pure capacitance; (B) a capacitance plus series resistance; (C) a pure inductance; (D) an inductance plus a series resistance.

However, always remember that the ac voltage we measure across any device is the voltage across the total opposition or impedance of that device. Fig. 28-1 shows the relationships. At A we have shown a device that contains only a capacitor. The phase relationship between the circuit current and the voltage across the terminals of the device is shown at the right; the voltage lags 90° behind the current because the impedance is made up solely of the reactance of the capacitor. If there is any appreciable resistance in the device, however, as shown at B, the phase angle is less than 90°. This device may be an electrolytic capacitor, since an electrolytic does have appreciable internal resistance.

If the impedance of a coil were made up of the coil reactance only, as at C, the coil voltage would *lead* the current by 90°. However, there is probably no coil that has so little resistance that it will act as a pure inductance. Every coil has some ac resistance, and it is always greater than the dc resistance because of skin effect, dielectric losses, and, in iron-core coils, core losses. The skin effect is the tendency of alternating currents to flow only along the surface of the wire rather than throughout its entire cross-section. At higher frequencies, these effects become much more noticeable. Thus, rf coils, which usually have low dc resistances, may have fairly high ac resistances.

The choke coil you will use in these experiments has a dc resistance of at least 400 ohms. Of course, its ac resistance is considerably higher. Unfortunately, there is no direct and simple method of finding its ac resistance; an ohmmeter will measure only the dc resistance.

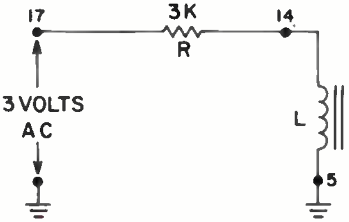


Fig. 28-2. Schematic of circuit used in Step 2.

To take this ac resistance into account, we treat the coil as though it were made up of a pure inductance in series with a resistance as in Fig. 28-1D. We can see what its total impedance is made up of with the aid of a vector diagram. The method we will use in this experiment is often called the 3-voltage vector method of finding the ac resistance and the inductive reactance of coils.

Experimental Procedure: For this experiment, you need the experimental chassis, tvom and the following:

1 3K-ohm resistor, 5%
2 .25-mfd capacitors

Set up the circuit shown in Fig. 28-2. To do this, unsolder and remove the two 1K-ohm resistors used in the last experiment and solder the 3K-ohm resistor in their place between terminals 14 and 17.

Connect the ground clip of the tvom to the chassis. Set the function switch to ac and apply power to your chassis. Touch the probe to terminal 17 and adjust the potentiometer until the voltage is exactly 3 volts, measured on the 3V range.

Step 1. To measure the ac voltage across the 3K-ohm resistor.

STEP NO.	NATURE OF MEASUREMENT	YOUR VALUE IN VOLTS	NRI VALUE IN VOLTS
1	VOLTAGE ACROSS R	1,56	1.5
2	VOLTAGE ACROSS L	2.36	2.25

Fig. 28-3. Results of Steps 1 and 2.

Connect the ground lead from the tvom to terminal 14. Apply power and touch the probe to the other end of the resistor at terminal 17. Read the voltage on the 3V ac scale. Record your reading for Step 1 in Fig. 28-3 as the voltage across R.

Step 2. To measure the ac voltage across the coil.

Clip the ground lead to the chassis and touch the probe to terminal 14. Read the voltage, and enter your reading in Fig. 28-3 as the voltage across L. Unplug the power cord.

Discussion: We are now going to show how the measurements you just made can be used to show that the phase angle between the voltage and current in the coil is less than 90°, and to compute the inductance and ac resistance of a coil. To illustrate our explanation, we will work out these characteristics for the coil on which we made measurements at NRI. In this experiment, you are to determine that the phase angle in your coil is less than 90°, but you do not have to compute the inductance and ac resistance unless you want to do so.

The NRI results for Steps 1 and 2 are given in Fig. 28-3. Yours will not necessarily be the same. If we consider the voltage drop across the coil to be exactly 90° out-of-phase with the voltage drop across the resistor, as it would be in a pure inductance, and add these values vectorially as in Fig. 28-4, our resultant is only 2.7 volts. Since this value is less than the source voltage of 3 volts, the voltage across the coil must not actually be 90° ahead of the resistor voltage. The reason is that the coil has considerable resistance. Using your readings, draw a vector diagram like that in Fig. 28-4 to show that the phase angle in your coil has to be less than 90°.

We don't know what the angle should be, and we can't calculate it without using rather complex mathematics. We can, however, use vectors to solve the problem. The method of doing so is shown in Fig. 28-5. Let's see how to use it.

We already know the three voltages for our vector diagram. What we do not know is the angle between them. To plot the angles, we start by using the voltage we measured across the series resistance

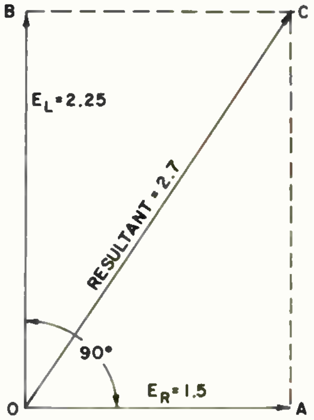


Fig. 28-4. The resultant, which is the vector sum of the voltages across the resistance and inductance, does NOT equal the source voltage.

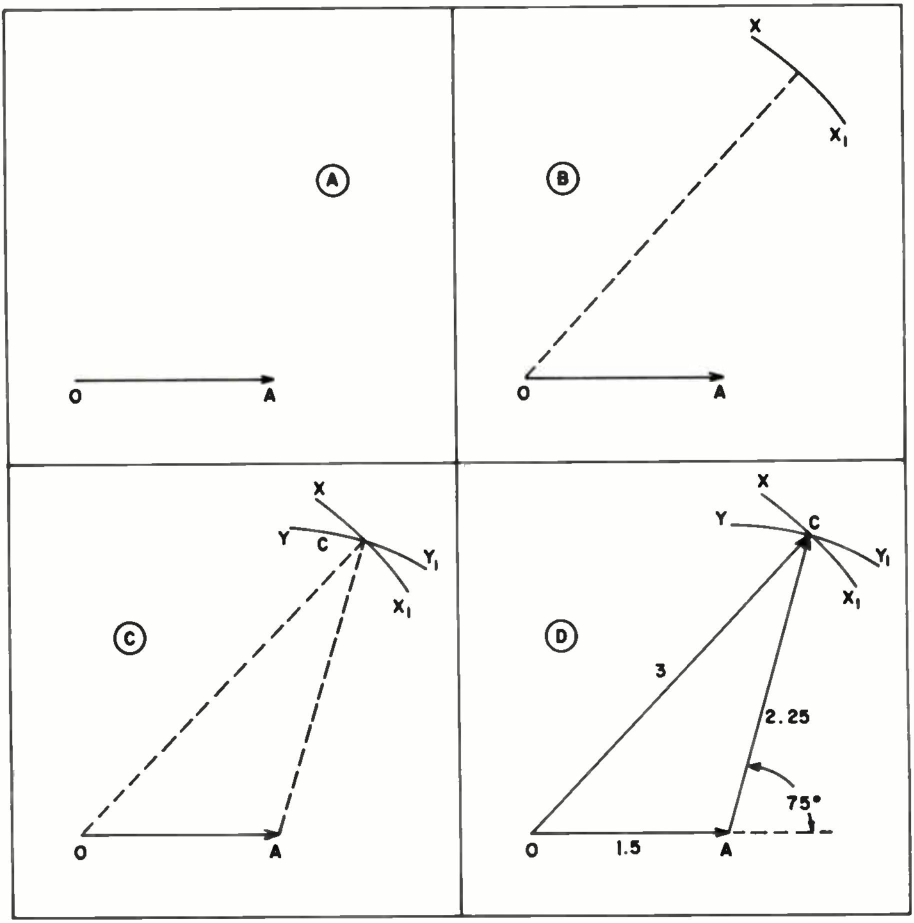


Fig. 28-5. How to use the three-voltage vector method of determining the voltage drop across the ac resistance of the coil, and the vector method of finding the voltage drop across the reactive component of the coil.

as a reference vector because it is in phase with the circuit current.

Using the figures shown in Fig. 28-3 for the coil we measured here at NRI, we plot a line, OA, to represent 1.5 volts. (The diagrams in Fig. 28-5 are *not* drawn to a scale of 1 inch equals 1 volt because of space limitations.) Now, draw your line OA to represent the voltage you measured across the 3K-ohm resistor. Use a scale of 1 inch equals 1 volt.

Using this same scale, we know that the resultant, which we have called OC in our previous vector diagrams, will be 3 inches long; it is our source voltage. It will start at point O. So the next thing we do is to use an ordinary drafting compass to draw an arc, using point O as the center, with a radius of 3 inches. This arc is called X-X_1 in Fig. 28-5B. Point C will fall somewhere on this arc.

As you learned earlier, line AC will be the same length and at the same angle as the other voltage vector, which we called OB in previous diagrams. In this case it is the voltage across the coil, which is 2.25 volts. Therefore, we draw another arc. This time the radius is 2.25 inches, and we use point A as the center. This is called Y-Y_1 in Fig. 28-5C. The point where these two arcs cross is point C. By drawing in lines OC and AC, as shown in Fig. 28-5D, we can find the phase angle between the coil voltage and the resistor voltage. In this vector diagram, the sides of the angle are made up of the line AC and the dashed line. This was explained previously in reference to Fig. 13D. For this particular coil, the angle is 75°. Since the resistor voltage and the circuit current are in phase, we know that the coil voltage is 75° ahead of the coil current.

You need not measure the angle; the important point to see is the phase angle between the current and voltage is less than 90° because the coil is not a pure inductance. This is as far as you need go in your calculations. However, we will show you how additional information can be obtained from these results.

So far, we have a vector diagram in which the sum of the voltage drops across the impedance of the coil and across the series resistance is equal to the source voltage. By using this information, we can find the voltage drops across the reactance and the ac resistance of the coil. From these, we can find the inductance and the ac resistance.

We can consider that the voltage across the coil impedance is the vector sum of two voltages 90° out-of-phase -- one across a pure inductance and one across a resistance.

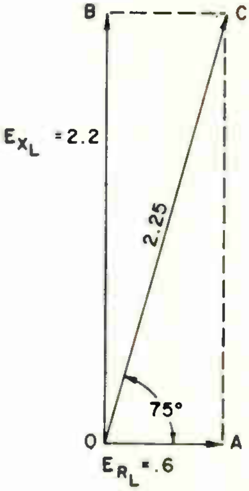


Fig. 28-6. How we find the voltage drop across the reactance and the ac resistance of the coil.

Therefore, we can draw another vector diagram using the coil voltage (line AC in Fig. 28-5D) as the resultant, as shown in Fig. 28-6. In this diagram we call this line OC. We know that it is 75° from the reference vector, and that the voltage across the coil resistance (E_{R_L}) is 90° out-of-phase with the voltage across the coil reactance (E_{X_L}). Therefore, we can draw these voltage vectors at right angles to each other.

So far, we know the angle of the two voltage vectors, but not their length. To find the length, we draw a line down from point C to form a right angle with the horizontal line, to give us point A. Then, we draw another line across from point C to form a right angle with the vertical line, to give us point B. By measuring the length of these vectors, we can find the voltage they represent. For this particular coil, the voltage across the coil resistance (E_{R_L}) equals .6 volt, and the voltage across the coil reactance (E_{X_L}) equals 2.2 volts.

To find the reactance of the coil, we divided E_{X_L} by the current. To find the current, we go back to the voltage across the 3000-ohm series resistance, which we recorded in Fig. 28-3. Our value was 1.5. Dividing this by 3, we get .0005 amperes as the circuit current. Now, dividing E_{X_L} by the current, we have 2.2 divided by .0005, which give us 4400 ohms as the inductive reactance (X_L) of the coil.

To find the inductance, we use the formula:

$$L = \frac{X_L}{2\pi f}$$

where 2π is 6.28 and f is 60, the frequency of the power line voltage. Substituting our values, we have:

$$L = \frac{4400}{6.28 \times 60} = \frac{4400}{376.8} = 11.7 \text{ henrys}$$

We can find the ac resistance of the coil by measuring the length of line OA and dividing this voltage value by the value of the circuit current. The length of line OA is .6 inches, which represents .6 volt. The ac resistance of the NRI coil works out to be .6 ÷ .0005 = 1200 ohms. Notice how much higher the ac resistance is than the dc resistance. The dc resistance of the coil we used was only 400 ohms.

You can determine the inductance and ac resistance of your coil if you wish to do so, but this is not necessary. However, be sure you understand that the ac resistance of a coil is much higher than the dc resistance, and also that the phase angle between the current and voltage in a coil is less than 90° because of the ac resistance of the coil.

Instructions for Statement No. 28: For this statement, you are to find out what happens to the circuit current when a capacitor is placed in parallel with the choke coil in a circuit like that shown in Fig. 28-7. Connecting a capacitor between the terminals of the choke coil provides another path, parallel to the one through the choke coil. Therefore, it would appear that the current through the resistor should increase.

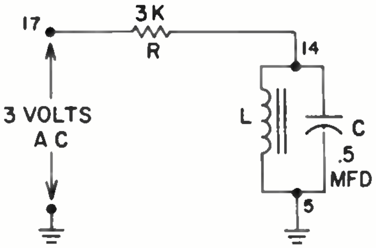


Fig. 28-7. Schematic of circuit used for Statement 28.

With the chassis connected as in Fig. 28-2, plug in the voltage divider, and adjust the potentiometer to get exactly 3 volts at the output between terminal 17 and ground. Measure the voltage across the 3K-ohm resistance and make a note of your reading in the margin of this page. 1.6V

Unplug the chassis, and set up the circuit shown in Fig. 28-7. Connect the two .25-mfd capacitors in parallel from terminal 5 to terminal 14. The two capacitors have a total capacitance of .5 mfd. Apply ac power and adjust the input to 3 volts. Note that the capacitors are in parallel with the choke coil. Now, mea- .31V sure the voltage across the resistor again. Compare this reading with your previous reading and answer the Statement below and on the Report Sheet.

Unplug the voltage divider; then unsolder and remove the two .25-mfd capacitors. Leave the 3K-ohm resistor connected to terminals 14 and 17.

Statement No. 28: When I connected the capacitors in parallel with the choke coil, I found that the circuit current, as indicated by the resistor voltages, was:

(1) the same as
(2) higher than
[✓ *(3)*] *lower than*

it was before the capacitors were connected.

EXPERIMENT 29

Purpose: to show that when a coil and a capacitor are connected in series across a source of ac voltage, the reactance of one tends to cancel that of the other, thus causing the circuit current to increase.

Introductory Discussion: The measurements you have made so far in your ac experiments have shown only that coils and capacitors offer a definite amount of opposition to the flow of alternating currents, and that the voltage across a coil or capacitor is out-of-phase with the current flowing through the device.

We know that the voltage across the inductive reactance of a coil leads the current through the coil by 90°, and that the voltage across a capacitor lags 90° behind the current through the capacitor. Therefore, when a coil and a capacitor are connected in series so that the current flowing through one also flows through the other, the voltages across the capacitor and the inductive reactance of the coil are 180° out-of-phase. As a result, the two voltages tend to cancel each other and the net voltage across the combination of the coil and the capacitor is the difference between them.

If the voltage across the capacitor is greater than the voltage across the coil, the net reactance will be capacitive and the combination will act like a capacitor. On the other hand, if the voltage across the coil is greater, the net reactance will be inductive, and the combination will act like a coil. However, if the two voltages are equal, there will be no reactance -- the only opposition to the circuit current will consist of the ac resistance of the coil and whatever other resistance there may be in the circuit. This condition is known as resonance.

In this experiment, you will first connect a capacitor in series with a resistor and determine the opposition (impedance) the capacitor offers to the flow of ac. You will then place your choke coil in series with the capacitor and the resistor and note the effect on the circuit current. If the current increases, you know that the coil must have reduced the impedance of the circuit. This is evidence that the coil has partly cancelled the opposition of the capacitor to the flow of current.

The amount of cancellation effect any given coil has depends on the capacitance value used with it. This can be shown either mathematically or experimentally. For the experimental approach, we will connect various capacitance values in series with a given coil and measure the voltage drops across the coil and capacitor. When the voltage across the reactive component of the coil equals the voltage across the capacitor, the circuit is at resonance. You will also see that at resonance the voltage across the capacitor and the voltage across the coil may actually exceed the source voltage.

Experimental Procedure: In addition to the ac voltage source, with the 3K-ohm resistance connected to it and your tvom, you will need:

- 2 .25-mfd capacitors
- 1 .1-mfd capacitor

The 3K-ohm resistor should still be connected to terminal 17 of the ac voltage source. Therefore, to form the series circuit shown in Fig. 29-1, unsolder the choke lead from terminal 14 and connect a .25-mfd capacitor from terminal 14 to terminal 5. Solder both connections. Connect the tvom test leads to terminal 17 and the chassis. Apply power to the circuit, and adjust the potentiometer to produce an output of exactly 5 volts. Use the 12-volt range of your tvom.

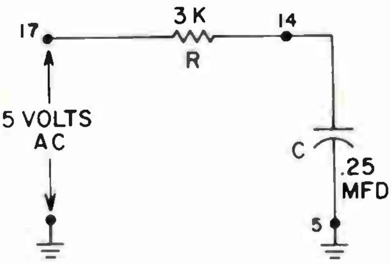


Fig. 29-1. Schematic for Step 1.

VOLTAGE MEASURED ACROSS	VALUE
3000 - OHM RESISTANCE	1 35
.25- MFD CAPACITOR	5.0

Fig. 29-2. Results of Step 2.

Step 1. To measure the ac voltage drops across the 3K-ohm resistor and the capacitor.

Connect the ground clip to terminal 14, and touch the probe to terminal 17 of the potentiometer. Enter your reading in Fig. 29-2. Then touch the probe to terminal 5 to measure the voltage across the capacitor, and again enter your reading in the proper space in Fig. 29-2. Unplug the power cord.

Step 2. To determine the effect of adding a coil to the series circuit.

Rewire your circuit as shown in Fig. 29-3. Move the capacitor lead from terminal 14 to terminal 6. Reconnect the free choke lead to terminal 14 and move the other choke lead from terminal 5 to terminal 6.

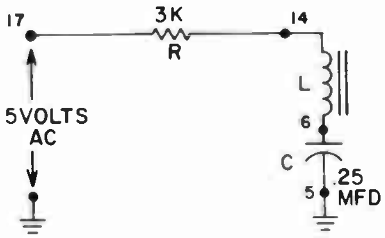


Fig. 29-3. Schematic of circuit used in Step 2. We change capacitor values in Step 3.

VOLTAGE ACROSS	VALUE	NRI VALUE
R	2.2	2.2
L	3.2	3.4
C	7.7	6.5

Fig. 29-4. Record the values found in Step 2.

When you have the circuit set up, apply power to the voltage divider, and adjust the potentiometer for a voltage of exactly 5 volts between terminal 17 and ground.

Connect the ground clip of your tvom to the junction of the resistor and the choke at terminal 14. Touch the probe to terminal 17 of the potentiometer, and measure the voltage drop across the 3K-ohm resistor. Record this reading in the first space in Fig. 29-4. Now, touch the probe to the junction of the choke and capacitor at terminal 6 and measure the voltage across the choke coil. Record your reading in Fig. 29-4.

To measure the voltage drop across the capacitor, move the ground lead of your tvom to the chassis, and touch the probe to terminal 6. Record your reading in Fig. 29-4. (Your readings may not be exactly the same as ours.)

To see if the current has increased, compare the voltage across the resistor in Fig. 29-2 with the reading you recorded in Fig. 29-4. Also, notice the voltages you have recorded for the capacitor and coil in Fig. 29-4.

Step 3. To show the effect on circuit conditions when different values of capacitance are used in combination with the coil.

Use the same circuit shown in Fig. 29-3, but change the value of the capacitor according to the values listed in the first column in Fig. 29-5. Take the measurements exactly as you did in Step 2. However, each time you connect a different value of capacitor in the circuit, make sure you connect the tvom leads from terminal 17 to ground, and set the ac source for a voltage of exactly 5 volts.

Connect a .1-mfd capacitor into the circuit and take the necessary voltage measurements. Record the values. You already have the voltage values for a .25-mfd capacitor in the circuit. Enter the values you recorded in Fig. 29-4 in the proper spaces in Fig. 29-5. You can form a .35-mfd capacitor by connecting a

CAPACITANCE	PARALLEL CAPACITOR COMBINATION	COIL VOLTAGE	CAPACITOR VOLTAGE	RESISTOR VOLTAGE
.1MFD	ONE .1 MFD	.86	5.8	.68
.25MFD	ONE .25MFD	~~[illegible]~~ 3.2	7.7	2.2
.35MFD	.25 MFD AND .1 MFD	5.0	8.2	3.2
.50MFD	TWO .25MFD	6.3	6.6	4.0
.60MFD	TWO .25MFD AND .1 MFD	6	6.6	4.2

Fig. 29-5. Results of Step 3.

.25-mfd capacitor in parallel with the .1-mfd capacitor. In a similar way, make up a .5-mfd by putting the two .25-mfd capacitors in parallel, and a .6-mfd by using the two .25-mfd capacitors and the .1-mfd capacitor in parallel. Measure the voltage across the coil, the voltage across the capacitor, and the voltage across the 3K-ohm resistance for each value of capacitance. Record your reading in Fig. 29-5.

When you have completed the readings needed for Fig. 29-5, unplug the voltage divider and unsolder and remove the capacitors and the resistors from the circuit.

Discussion: To show that the voltage drops across the coil and capacitor must in some way oppose or cancel each other, let us use the NRI values in Fig. 29-4 to draw the vector diagram in Fig. 29-6. We must take one additional measurement, however. This is the drop across the coil and the resistor. From this vector, we can determine the phase relationships, the resultant voltage differences in the circuit; and from these voltages, compute the total circuit reactance. You are not required to draw the vector or compute the reactances in this experiment. However, you may do so if you wish.

We can get a great deal of information from the vector diagram in Fig. 29-6. For example, the angle formed by lines BC and BD tells us that the voltage across a coil leads the voltage across the resistor (line OB, which is used here as the reference) by less than 90°. The line, CD, tells us that there is a voltage drop of 3.07 volts across the coil reactance (E_{X_L}), and the short line BD indicates that the voltage drop across the ac resistance of the coil is 1.45 volts.

Line DE is the voltage drop across the reactance of the capacitor (E_{X_C}). We learned in Experiment 27 that the voltage drop across a capacitor is 90° out-of-phase with the source voltage in the circuit. Thus, line DE is drawn straight downward from point D. The length of this line corresponds to 6.5 volts -- the voltage drop across the capacitor.

We now have the voltage drop across the inductive reactance (line CD) and the voltage drop across the capacitive re-

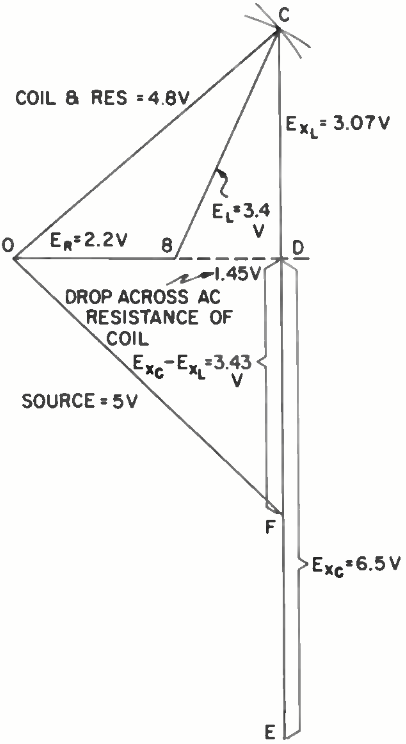


Fig. 29-6. Complete vector diagram of voltage relationship in a circuit consisting of a capacitor, a coil, and resistance connected across a source of ac voltage.

actance (line DE). As you learned in Step 2 of this experiment, these reactances oppose each other, and the net reactance or opposition to the current flow is the difference between the two voltage drops. This is shown in the diagram in Fig. 29-6. Beginning at point E, we subtract 3.07 volts, the length of line CD, from line ED. This leaves a total of 3.43 volts (line DF) as the net drop across the circuit reactance. We can prove that the length of line DF is actually the voltage drop across the net reactance by measuring the line from point F to point O. This is 5 volts -- the voltage of the source.

With this information, we can compute the circuit reactances and see that adding the coil *does* reduce the total reactance in the circuit. To compute the reactance, we divide the voltage drop across the reactance by the amount of current in the circuit, or R = E/I. The current, of course, is equal to the voltage drop across the 3000-ohm series resistor (2.2 volts) divided by 3000, or I = E/R. This works out to be approximately .0007 ampere.

Using the reactance formula, we find that the reactance of the capacitor alone is approximately 10,400 ohms. But when we compute the net reactance in the series circuit, as indicated by line DF in Fig. 29-6, we find that it is approximately 4900 ohms. (We compute the reactance by dividing the net voltage, 3.43 volts, by the circuit current, .0007 amperes.) From this we can see why the voltage drop across the components increased when we put the coil in the circuit. The voltage drops across the coil and capacitor actually opposed each other to produce a lower net reactance in the circuit, which caused an increase in the circuit current. This was indicated by the increase in the voltage drops across the circuit components.

In Step 3, you varied the capacitance value in the series circuit, and from your results that you recorded in Fig. 29-5, you should notice that the voltage drops across the components increased as you increased the value of the capacitance. You may notice that with one value of capacitance, the voltage drops reach their highest values. The fact that the higher voltage drops exist in the circuit shows that the circuit reactance must have become very low. This point is the resonance point for the coil-capacitor combination.

As you increased the capacitance further, you probably noticed that the voltage drops began to decrease. It is not necessary for you actually to reach resonance in this experiment. It is important only that you understand that the voltage drops across the coil-capacitor combination in a series circuit increase as the circuit capacitance is increased.

The resonant point of the series-resonant circuit can be shown graphically as in Fig. 29-7. Notice from the graph

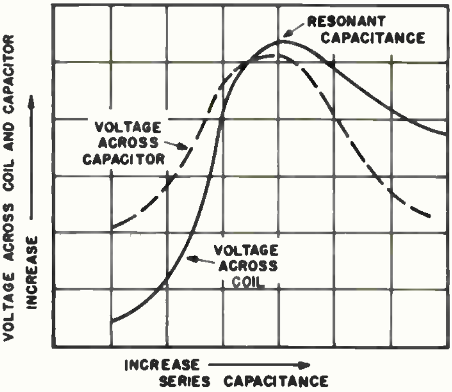


Fig. 29-7. Resonance in a series-resonant circuit.

that the voltage drops across the coil and capacitor increase with an increase in capacitance until a value is reached where both curves reach a maximum. This is the resonant point in the circuit. As the capacitor value is increased further, the voltage drops decrease, as indicated by the curves.

Instructions for Statement No. 29: You need not take any additional readings. Just examine the voltage readings you took across the capacitor in Fig. 29-5, and answer the Statement.

Statement No. 29: The highest voltage that I measured across the capacitor was:

[✓ *(1) higher than*]
(2) lower than
(3) equal to

the source voltage.

EXPERIMENT 30

Purpose: To show that shunting a capacitor across an inductance in an ac circuit will cause the line current to decrease; and

To show that when the reactance of the coil equals the reactance of the capacitor, the line current becomes a minimum, indicating that the combination has a high impedance.

Introductory Discussion: As you demonstrated in the preceding experiment, the principal characteristic of a series-resonant circuit is that at resonance it acts like a low resistance. This, of course, produces a high current through the circuit and a high voltage drop across the coil and capacitor. There are many circuit applications, however, in which the opposite effect is desirable. One of many practical examples of this is a wave trap designed to filter out undesired frequencies at the input of a radio or television receiver.

As you learned in your lessons, a parallel-resonant circuit at resonance acts like a high resistance. You will prove this by measuring the current in a circuit in which you will connect various capacitors in parallel with the coil.

The current in this circuit must divide between the two components. Part of the current will flow through the capacitor and the remainder through the coil. The circuit acts like a high resistance because the currents of the two branches are 180° out-of-phase. (This is just the opposite of the conditions in a series-resonant circuit, in which the voltages are 180° out-of-phase.) The net circuit current, which is the difference between the currents in the two branches of the parallel circuit, is, therefore, relatively small. In fact, it is just large enough to make up for the losses in the parallel-resonant circuit. As in a series-resonant circuit, these losses are due primarily to the ac resistance of the coil.

If you had an instrument sensitive enough, you could measure the current through the coil as various capacitors were connected across it. As you approached resonance, you would find that there was an increase in the current flowing in the parallel circuit, which would be accompanied by a corresponding decrease in the current in the rest of the circuit. With the equipment we have at hand, however, you can measure only the current flowing through the entire circuit with any degree of accuracy. Therefore, we shall assume that the impedance of the parallel-connected coil and capacitor is at its maximum when the circuit current is at its minimum.

Experimental Procedure: You need the experimental chassis, tvom and the following:

- 2 .25-mfd capacitors
- 1 .1-mfd capacitor
- 1 1K-ohm resistor
- 1 18K-ohm resistor

Construct the circuit shown in Fig. 30-1. Replace the 3000-ohm resistor with a 1000-ohm resistor. Then, unsolder the choke lead from terminal 6 and solder it to terminal 5.

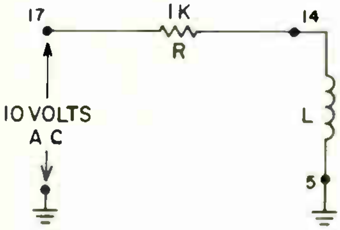


Fig. 30-1. Schematic of the circuit for Step 1.

Apply power to the circuit, and adjust it to produce a voltage of exactly 10 volts across the output of the ac voltage divider between terminal 17 and the chassis.

Step 1. To find the current through the coil and the resistor.

Measure the voltage drop across the 1K-ohm resistor by connecting the ground clip of the tvom to terminal 17 and the probe to terminal 14. Since the resistance is 1K-ohms (± 10%), the current (in milliamperes) through it is the same as the voltage across it in volts.

For example, our measurement for this step was 1.6 volts. Dividing this by 1000 to get the current in amperes gives a value of .0016, which is 1.6 milliamperes -- numerically the same as the voltage value. Record your voltage reading on the first line of Fig. 30-3. (It may not be the same as ours.) Unplug the line cord.

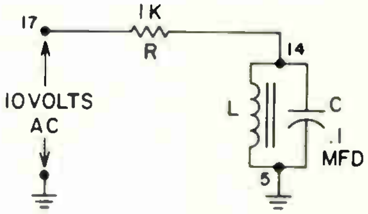


Fig. 30-2. The circuit for Step 2.

Step 2. To show that the circuit current decreases when a capacitor is connected across the choke coil.

Solder a .1-mfd capacitor across the terminals of the choke coil to form the circuit shown in Fig. 30-2, adjust the voltage between terminal 17 and ground to exactly 10 volts, and again measure the voltage drop across the 1K-ohm resistor.

STEP NO.	CAPACITANCE (IN MFDS)	VOLTAGE ACROSS RESISTOR	
		YOUR VALUE IN VOLTS	NRI VALUE IN VOLTS
1	NONE	1.85	1.6
2	.10	1.5	1.2
3	.25	1.0	.8
	.35	.66	.7
	.50	.25	.35
	.60	.35	.5

Fig. 30-3. Record results for Steps 1, 2, and 3.

Enter your voltage reading on the second line of Fig. 30-3.

Step 3. To show how the circuit current varies as different values of capacitance are connected across the coil.

Replace the .1-mfd capacitor in turn with each capacitance listed for Step 3 in Fig. 30-3. (These values of capacitance are the same as those you used in the previous experiment, and are formed the same way.) Each time the capacitance is changed, be sure to readjust the input voltage to exactly 10 volts, and then measure the voltage drop across the resistor. You need not measure the voltage drops across the coil and capacitor in this step. Enter your readings in Fig. 30-3.

When you have finished making the measurements, unplug the power cord.

Discussion: As in the previous experiment, you may not be able to actually go through resonance with the coil-capacitor combination. This is unimportant because from your readings in Fig. 30-3 you can see that as the capacitance increases, the circuit current decreases. From the typical values in Fig. 30-3, you can see that we reached resonance with a .5-mfd capacitor.

In a parallel-resonant circuit, then, the circuit is at resonance when the circuit current is at a minimum, as shown by the curve in Fig. 30-4. Compare this curve with the one shown in Fig. 29-7. From these you should be able to see the difference between the two resonant circuits.

Instructions for Statement No. 30: We have mentioned several times that a solid-dielectric capacitor normally has very little ac resistance. For your report on this experiment, you will place a given amount of resistance in series with the capacitor in the parallel-resonant circuit and see what happens to the circuit current.

Set up the circuit shown in Fig. 30-5,

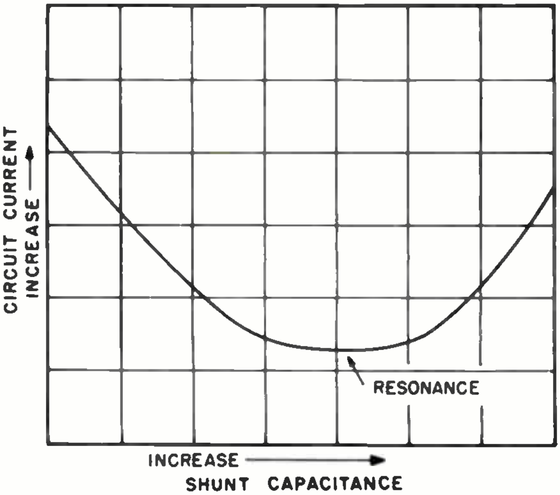


Fig. 30-4. Resonance in a parallel-resonant circuit.

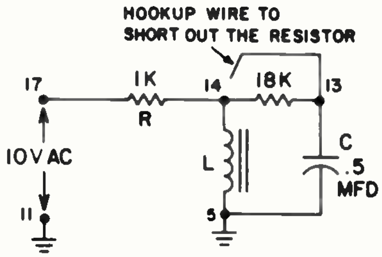


Fig. 30-5. Schematic of the circuit used in your experiment.

using .5-mfd for capacitor C. You should still have a .1-mfd and two .25-mfd capacitors connected between terminals 5 and 14. Remove the .1-mfd capacitor. You now have .5 mfd in parallel with the coil. Disconnect the leads of the two .25-mfd capacitors from terminal 14 and connect them to terminal 13. Leave the other leads of the capacitor combination connected to terminal 5. Then, connect an 18K-ohm resistor between terminals 13 and 14. You should still have a 1000-ohm resistor connected from terminal 14 to terminal 17.

Prepare a 4 or 5" length of hookup wire and solder one end to terminal 13. Arrange the other end of the piece of wire so that you can conveniently touch it to terminal 14 when you are instructed to do so. Solder all connections.

When you have the circuit set up, connect the tvom ground clip to the chassis and clip the probe to potentiometer terminal 17. Adjust the voltage to exactly 10 volts. Next, move the tvom ground clip to terminal 14 and the probe to terminal 17 and touch the short length of hookup wire that you soldered to terminal 13 to terminal 14. Measure the voltage across the 1K-ohm resistor, and make a note of the reading.

.2 V

Disconnect the hookup wire from terminal 14 and note whether the voltage across the 1K-ohm resistor increases, decreases, or remains unchanged. When you have found out what happens, unplug the power cord. Now complete the Statement below and on the Report Sheet.

Unsolder the resistors and the capacitors from the terminals, and lay them aside for future experiments.

Statement No. 30: When I removed the short, placing an 18K-ohm resistor in series with a capacitor, the circuit current:

(1) remained unchanged.
[✓ *(2) increased.*]
(3) decreased.

LOOKING AHEAD

Now that you have completed the experiments that demonstrate the fundamental properties of resistors, coils, and capacitors in ac and in dc circuits, you are ready to combine these components into more complex circuits. In your next group of experiments, you will demonstrate how power supplies work. A knowledge of power supply operation is important to you because power supplies are used to provide dc voltages in radio and television receivers. You will carry out experiments using solid state rectifiers as well as vacuum tube rectifiers.

After you have entered all your answers on the Report Sheet, send it to NRI for grading. While you are waiting for the next kit to arrive and the Report Sheet to be returned to you, gather all the parts you have left over from this kit and the previous kits, and put them in a safe place. The parts left over are shown in Table I.

After you have received a passing grade on your Report Sheet, you can unsolder and disconnect the choke, leads, and the connections to the potentiometer. Remove the flashlight cells, the potentiometer and the potentiometer mounting bracket. Remove the excess solder from the terminals and the parts.

1	.1 mfd tubular capacitor
2	.25 tubular capacitors
2	20 mfd, 150V electrolytic capacitors
1	1K-ohm potentiometer
1	500K-ohm potentiometer w/switch
1	Potentiometer mounting bracket
1	220-ohm resistor
1	470-ohm resistor
1	680-ohm resistor
3	1K-ohm resistors
1	3K-ohm resistor, 5%
1	3.3K-ohm resistor
2	4.7K-ohm resistors
1	6.8K-ohm resistor
2	10K-ohm resistors
1	15K-ohm resistor
1	18K-ohm resistor
2	22K-ohm resistors
1	47K-ohm resistor
1	82K-ohm resistor
3	100K-ohm resistors
1	220K-ohm resistor
1	470K-ohm resistor
1	1-megohm resistor
1	1.8-megohm resistor
2	10-megohm resistors
2	Silicon diodes
2	1.5V flashlight cells
1	Experimental chassis w/parts attached
1	Alligator clip
1	Etched circuit board w/7-pin tube socket
1	Marking crayon
	Hookup wire
	Solder
	Miscellaneous hardware

Table I. Leftover parts to be stored for later use.

HOW DO YOU FEEL?

A theory has been advanced (and to a large extent scientifically proven) that people feel good and feel bad in cycles.

Psychologists say that for a certain number of days you will be "sitting on top of the world." Then for a longer period of time you will feel about average. Then for a while you may be depressed – "in the dumps" -- have the "blues."

Then the cycle starts over again. It is claimed you can keep a record of the way you feel, and predict accurately about when you will be feeling grand -- or when you will be depressed. Be this as it may, we DO know that no matter how black things look at times, conditions always seem to improve. It's a very, very true saying that "every cloud has a silver lining." Perhaps this old saying is really based on the scientific theory I mentioned above.

And since you and I both know that we are bound to "snap out" of periods of depression, let's resolve never to make important decisions while feeling "low".

Don't fuss with a friend -- don't quit a good job – don't give up a worthwhile ambition just because you are in a "depressed cycle." Tomorrow, or next week you'll feel better!

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ACHIEVEMENT THROUGH ELECTRONICS

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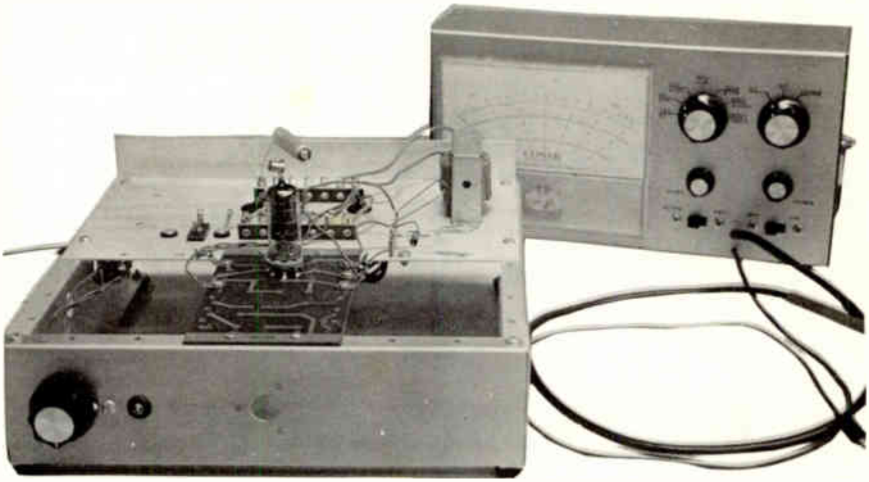
PRACTICAL DEMONSTRATIONS OF RADIO-TV FUNDAMENTALS



INDEX OF SECTIONS

JP1M276

1976 EDITION

Litho in U.S.A.

INSTRUCTIONS FOR PERFORMING EXPERIMENTS 31 THROUGH 40

This part of your training program covers power supplies, tube fundamentals and transistor fundamentals. The experiments in this training kit are especially important because the knowledge and experience you gain will be of great value in your practical work.

You will study power supplies in some detail in this kit. You will build and investigate several types of rectifier circuits, filter networks, voltage regulators, and voltage doublers. Such broad coverage will enable you to understand nearly all of the power supply configurations currently in use and will give you self-confidence in your service work.

Following the work on power supplies, you will perform experiments on tube fundamentals and transistor fundamentals. You can see the importance of this when you realize that a tube or transistor is used in the vast majority of circuits which amplify, oscillate or perform any other active function. In addition to learning how these devices work, you will prepare yourself for work with amplifier, oscillator, mixer and other circuits which you will study in the following training kits.

HOW TO AVOID ELECTRICAL SHOCKS

As you get further along in your Practical Training Course, it becomes more and more important to take precautions to avoid electrical shocks.

One side of almost every power line is grounded. When you stand on the earth, you are at the same potential as everything else in contact with the earth, including the grounded side of the power line. So if you touch the other side of the power line, your body will complete the circuit to ground. If you are insulated from the earth, you can touch the other side of a power line and not get shocked. However, you should not touch a water pipe, a radiator, or a concrete floor at the same time, because they are at ground potential with respect to the high side of the line.

In ac-dc receivers, which operate on either ac or dc power line voltages, the ungrounded side of the power line connects to the receiver circuits, and in some cases directly to the chassis. Here an external ground must not be fastened to the chassis. Unless polarized plugs and receptacles are used the power cord plug may be inserted into the wall outlet so that the chassis is connected to the high side of the power line. A ground wire connected to the chassis, therefore, would short-circuit the power line and cause a house fuse to blow.

You can determine whether or not the chassis is at ground potential by measuring the ac voltage between a known grounded object and the chassis. If you read ac line voltage, remove the line plug, turn it over and measure the voltage again. It should be zero, which means that you can touch the chassis without being shocked.

A power line is not the only source of

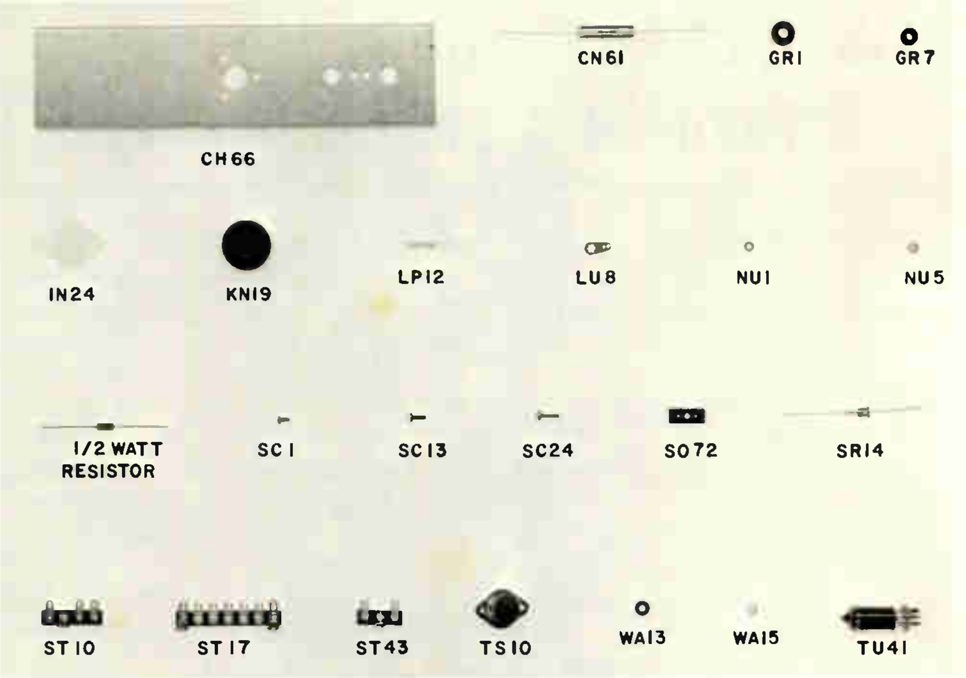


Fig. 1. The parts you received in this kit are pictured above and listed below.

Quan.	Part No.	Description	Price Each
2	CH66	Chassis rail	.79
1	CN61	20-mfd, 150V electrolytic capacitor	.65
1	GR1	3/8" rubber grommet	12/.25
1	GR7	5/16" rubber grommet	.06
1	IN24	Transistor insulator	.28
1	KN19	Knob	.55
1	LP12	Neon lamp type NE83	.26
5	LU8	Terminal lug	12/.15
12	NU1	6-32 hex nut	12/.15
9	NU5	4-40 hex nut	12/.15
1	RE26	100-ohm resistor	.15
1	RE58	2.2K-ohm resistor	.15
9	SC6	1/4" X 4-40 screw	.15
10	SC13	3/8" X 6-32 screw	12/.15
2	SC24	1/2" X 6-32 screw	12/.25
1	SO72	Transistor socket	.07
2	SR14	High voltage silicon diode	.80
1	ST10	3-lug terminal strip	.05
1	ST17	7-lug terminal strip	.12
1	ST43	2-lug terminal strip	.06
1	TS10	Power transistor	1.08
1	TU41	12BA6 tube	1.05
2	WA13	Fiber shoulder washer	12/.15
15	WA15	No. 6 lockwasher	12/.15

Resistors are 1/2 Watt, 10%

electrical shocks. The B supply in a receiver may be even more dangerous, since in ac sets there may be several hundred volts between B+ and the chassis. You must observe the same precautions in working with the B supply as you do when working with a power line.

Make your work space safe. If you have provisions for an antenna and ground at your bench, the ground should be where you will not accidentally touch it. If water pipes are nearby, cover them with insulating shields so you cannot accidentally hold on to one while working with a chassis. If the floor is concrete, provide a platform of dry boards, without nails going through the boards to the concrete. For a stool with metal legs put an insulating caster under each leg.

Do not be afraid of electricity, but respect it. Beginners almost never get shocked. Only when you grow overconfident and disobey safety rules is there a real danger of your being shocked. Keep alive your respect for electricity and its effects, and you will have nothing to worry about.

CONTENTS OF THIS KIT

The contents of this kit are pictured in Fig. 1 and are listed below it. Check the parts you received against this list to be sure you have all of them. Do not discard any of these parts, or the parts from previous kits unless instructed to do so or until you have finished your NRI course; you will use the parts again in later experiments.

IMPORTANT: If any part of this kit is missing, look for a substitute part or special instruction sheet. If any part is obviously defective or has been damaged in shipment, return it immediately to NRI as directed on the packing slip accompanying this kit.

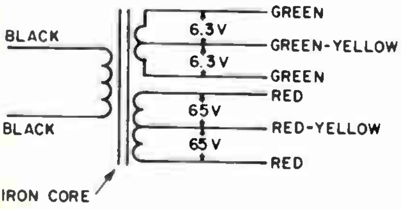


Fig. 2. Schematic symbol for power transformer.

THE POWER TRANSFORMER

The power transformer which you received in Kit 3 may be called a "combination" transformer, because it furnishes both high and low ac voltages from a given ac line voltage. The symbol used to represent this transformer in schematic diagrams is shown in Fig. 2.

As the diagram shows, there are three separate windings on this transformer. The primary winding, which is wound for 117-volt, 60-Hz ac power, is terminated in the two black leads. Under no circumstances should you connect the primary of this transformer to a dc power line or to an ac power line having a frequency of 25 or 40 Hz. The low voltage winding is the one with green leads. It is center-tapped with a green/yellow lead. Each section, between either of the green leads and the center tap, supplies about 6.3 volts; the voltage between the two green leads is approximately 12.6 volts.

The third winding, having the leads colored red, is also center-tapped. This winding, which is commonly called the high voltage secondary winding, supplies the high voltage needed for the plates of the vacuum tubes. It is designed to have a no-load output of about 130 volts between the red leads. Variations in line voltage may make the actual no-load output of your transformer anywhere between 100 and 140 volts. The center tap is brought out to the red/yellow lead.

THE VACUUM TUBE

You received a type 12BA6 vacuum tube in this kit. This is a miniature type pentode and its schematic symbol is shown in Fig. 3A. The labels G_1, G_2 and G_3 represent the control grid, screen grid and suppressor grid; K is the cathode; P is the plate; and H is the heater or filament.

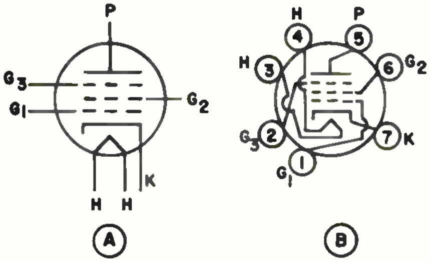


Fig. 3. (A) Schematic symbol and (B) basing diagram for a 12BA6 tube.

The 12BA6 fits a standard 7-pin tube socket, such as the socket you installed on your etched circuit board. The filament requires approximately 12.6V and the filament current is .3 amp.

Fig. 3B is a basing diagram of the 12BA6 tube. It shows the pin connections to the tube elements. The pins are numbered in a clockwise direction, counting from the open space when viewed from the bottom.

THE TRANSISTOR

You also received a power transistor in this kit. It is a germanium type PNP transistor in a TO3 case. The transistor has three elements: base, emitter and collector. The base and emitter have pin connections while the collector terminal is the transistor case. The schematic symbol for the transistor is shown in Fig. 4A and the elements are identified in Fig. 4B.

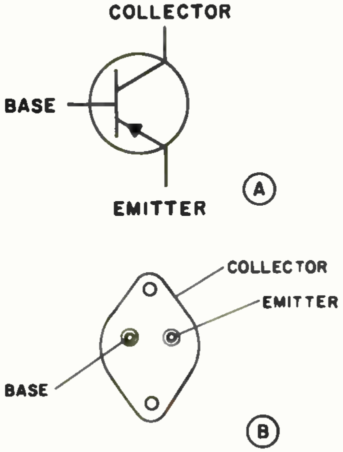


Fig. 4. (A) Schematic symbol and (B) basing of a PNP transistor with lead identification.

This transistor is designed to provide little amplification. However, it can pass high current. It will be mounted in such a manner that the chassis will serve as a heat sink and prevent the transistor from overheating.

SILICON DIODES

You received two solid-state silicon diodes (NRI part No. SR14) in this kit. We will call them high voltage or HV diodes to distinguish them from the diodes you received in Kit 1. These HV diodes can withstand up to 400 peak volts across their terminals. These HV diodes are commonly called "top hats" because of their appearance. The actual diodes are tiny pellets of silicon inside the plastic and metal package.

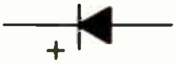


Fig. 5. The schematic symbol for a solid state diode.

Fig. 5 shows the schematic symbol for a solid-state diode. The diode has two elements – an anode represented by the arrow, and a cathode which is represented by the bar. The leads are usually identified by a + sign near the cathode lead or by a schematic symbol printed on the body of the diode. The cathode of the HV "top hat" diode is the lead that connects to the "brim" end of the case. Notice that this lead *connects directly to the metal case!* The anode lead comes from the top of the "top hat."

Preliminary Assembly

Before performing the experiments in this kit, you will have to make several changes in your experimental chassis. Most of the parts you will need are shown in Fig. 1. The others were included in the earlier kits.

PREPARING AND INSTALLING THE CHASSIS RAILS

You will need the following parts:

2	Chassis rails
1	3/8" rubber grommet
1	5/16" rubber grommet
1	3-lug terminal strip
1	2-lug terminal strip
9	3/8" X 6-32 screws
9	6-32 hex nuts
10	No. 6 lockwashers
1	500K-ohm potentiometer with On-Off switch

Make sure the power cord is unplugged. Unsolder and disconnect the leads of the power cord from the black leads of the power transformer. Also, unsolder the green lead from the 4-lug terminal strip.

Observe the two chassis rails which you received in this kit and the rail already attached to your chassis. Notice that the three are identical. Position one chassis rail as shown in Fig. 6, so that the two 3/8" holes are on the right, and the top and bottom lips of the rails are toward you. You will then have the inside of the rail facing you.

Install a 3/8" rubber grommet in the hole nearest the right end of the chassis rail. Squeeze the grommet into an oblong shape and push it into the hole so that the rubber completely lines the hole in the chassis.

Mount the 3-lug terminal strip on the inside of the same chassis rail. Position the terminal strip exactly as shown in Fig. 6. Pass a 6-32 screw through the rail from the outside. Place the foot of the terminal strip and a No. 6 lockwasher over the screw. Attach a hex nut and tighten the screw.

Pass the end of the power cord up through the grommet in the chassis rail. Tie an overhand knot in the cord approximately 2 inches from the end of the wire. Lay this chassis rail aside. Position the second rail as shown in Fig. 7.

Slip a control lockwasher over the shaft and bushing of the potentiometer and mount the potentiometer in the 3/8"

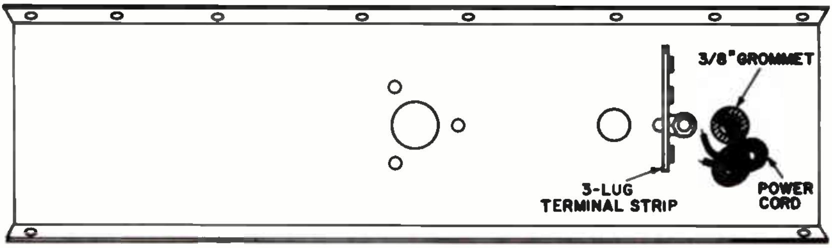


Fig. 6. The parts installed on the left chassis rail.

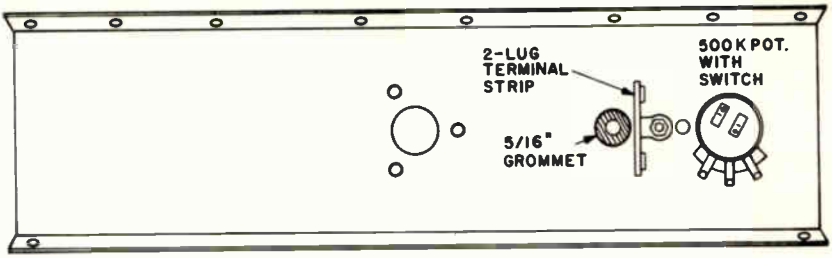


Fig. 7. Parts mounted on the front chassis rail.

hole nearest the end of the rail. Attach a control nut. Rotate the potentiometer so that the three terminals are in the positions shown in Fig. 7 and tighten the nut.

Install a 5/16" rubber grommet in the other 3/8" hole as shown in Fig. 7. This grommet will fit loosely in the hole. Mount the 2-lug terminal strip on the inside of your chassis rail near the rubber grommet. Position the terminal strip as shown in Fig. 7, and attach it securely, using a 6-32 screw, lockwasher and nut.

Next, you will fasten the chassis rails to the chassis plate. Remove the chassis rail from the front of the chassis plate. Set aside the 4-lug terminal strip. Using the same screws and nuts, mount this as the right chassis rail as shown in Fig. 8. Note that the lips are turned inward toward the center of the chassis plate and the rail extends beyond its front.

Fasten the chassis rail with the power cord and a 3-lug terminal strip to the left side of the chassis plate, as shown in Fig.

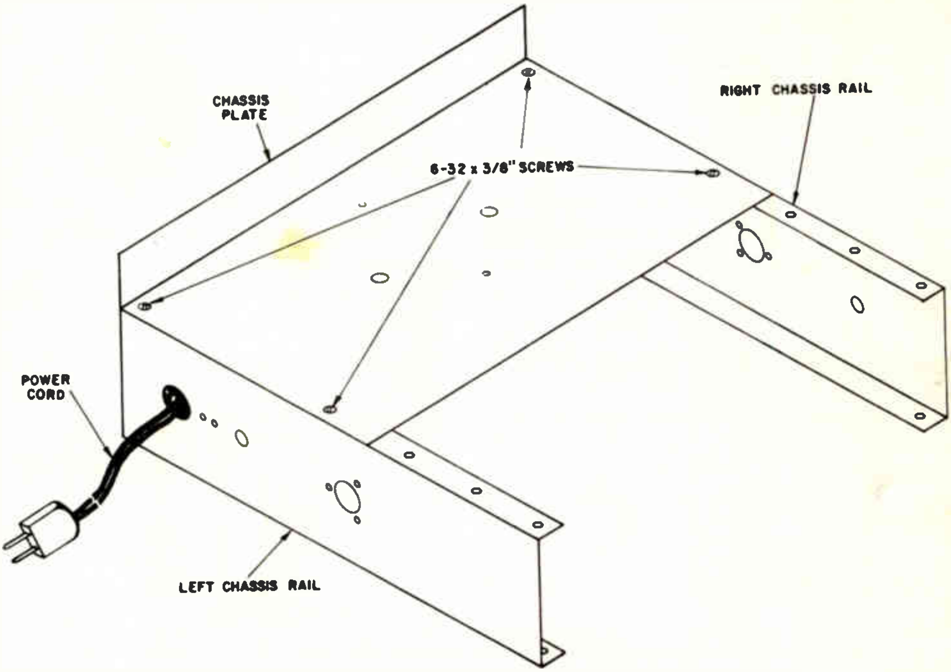


Fig. 8. Mounting the side rails on the chassis plate.

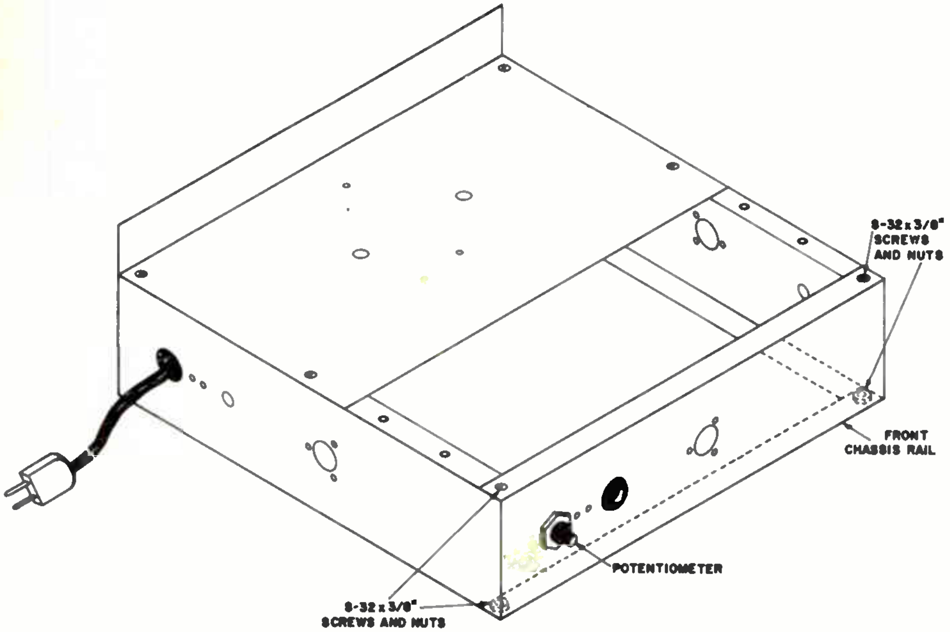


Fig. 9. Mounting the front rail on the chassis.

8. Secure with two 6-32 screws, No. 6 lockwashers and 6-32 hex nuts.

Next fasten the chassis rail with the potentiometer to the left and right side rails, to form a box as shown in Fig. 9. Notice that the top lip of the front rail fits *over* the top lips of the left and right side rails. Secure the front rail to the side rails with four 6-32 screws, No. 6 lockwashers and 6-32 hex nuts. Pass a screw through the top and bottom lip of both rails at each corner.

MOUNTING THE PARTS ON THE CHASSIS

Now, you will make changes on the chassis plate. You will need the following:

1	Power transistor
1	Transistor socket
1	7-lug terminal strip
1	3/8" X 6-32 screw
2	1/2" X 6-32 screws
1	Control knob
3	No. 6 lockwashers
3	6-32 hex nuts
2	Insulated shoulder washers
1	Transistor insulator

Remove the 3-lug terminal strip and solder lug from the left side of the chassis plate. Save the parts.

Mount the 7-lug terminal strip at holes F and I as shown in Fig. 10. Secure with the 6-32 screws and nuts just removed from the chassis. Reinstall the 4-lug terminal strip at hole U, as shown in Fig. 10. Use a 6-32 screw, No. 6 lockwasher and 6-32 hex nut.

Next, you will install the power transistor. The transistor mounts under the chassis at the location shown in Fig. 10. The transistor socket attaches to the pins which will project through holes C and C_3 in the chassis.

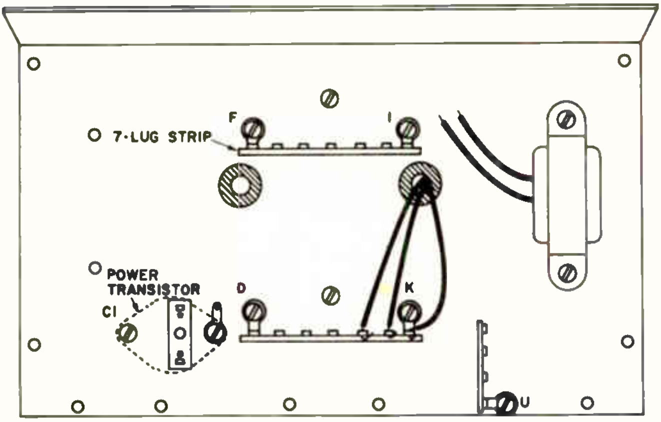


Fig. 10. Mounting the parts on the chassis.

Fig. 11 is an exploded view showing how to mount the transistor. Place the thin insulator over the transistor terminals. Place the solder lug and fiber shoulder washer over one of the two 1/2" X 6-32 screws. Slip a shoulder washer only over the other screw. Place the screw with the solder lug in transistor mounting hole C2 in the chassis and push the other screw through hole C1 so that the shoulder washers insulate the screws and the solder lug from the chassis.

Mount the transistor as shown in Figs. 10 and 11. Position the solder lug as shown in Fig. 10. Attach No. 6 lockwashers and 6-32 hex nuts and tighten the nuts just enough to compress the lockwashers.

Slip the transistor socket over the pins of the transistor. Install the control knob on the potentiometer shaft by lining up the flatted part of the shaft with the flat of the knob. Push the knob onto the shaft firmly.

WIRING THE CHASSIS

You now have a number of terminal strips and other parts mounted on the chassis plate and chassis rails. The simple terminal number system used in the earlier training kits would be a little awkward to use now that we have so many terminals. We will therefore change to a more flexible system.

If you have marked the terminal numbers on your chassis plate or a piece of tape with your crayon, you should now

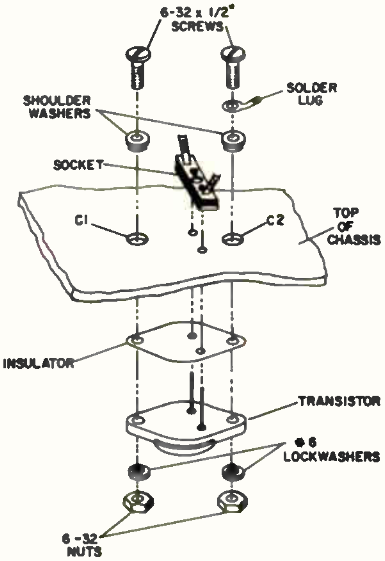


Fig. 11. Mounting the transistor on the chassis.

remove the markings. An ordinary pencil eraser or a soft cloth and a little liquid detergent will help you.

We will identify the terminals on the chassis by giving each terminal strip a letter designation. Each terminal will be completely identified by a letter and a number. Fig. 12 shows the terminals identified using this method. Notice, for example, the terminals on Strip A are called A1, A2, A3, etc., and those on Strip B are called B1, B2, B3, etc.

You will now connect the power transformer leads, the power cord and the on-off switch. Some of these connections are permanent. When instructed to make a permanent connection, remove about 1/4" of insulation from the end of the wire, bend a hook, slip the hook through the hole in the terminal and squeeze it closed with your longnose pliers.

Use only temporary connections on top of the chassis. The wiring is shown in Fig. 13.

Remove the tape from the red and red/yellow power transformer leads. Push the ends of these three leads of the power transformer up through the grommet in hole E of the chassis.

Connect one red lead to terminal B1 and solder the connection.

Connect the red/yellow transformer lead to terminal B2. Do not solder.

Connect the other red transformer lead to terminal B3.

You should have a green transformer lead connected to terminal B7 and the green/yellow lead connected to terminal B5. Move the green/yellow lead to B6 and connect the other green lead to B5 as shown in Fig. 13.

Connect the leads of the choke coil to terminals A6 and A7.

You will now perform the under-chassis wiring. Refer to Figs. 14A and B as you make the following connections. Each of these connections is to be permanent unless otherwise indicated.

Remove 1/4" of insulation from each end of the two 10" lengths of hookup wire. Twist the wires together to form a twisted pair.

At one end, connect one lead of the twisted pair to terminal D1 and connect the other lead to D2. Do not solder.

At the other end of the twisted pair connect one lead to terminal 4 of the on-off switch on the back of the potentiometer and connect the other lead to terminal 5 of the on-off switch. Solder

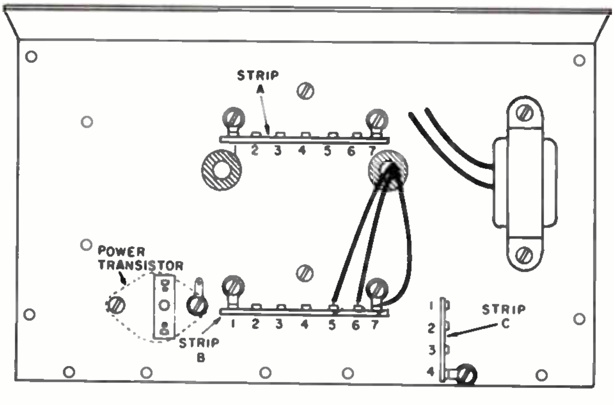


Fig. 12. Terminal identification.

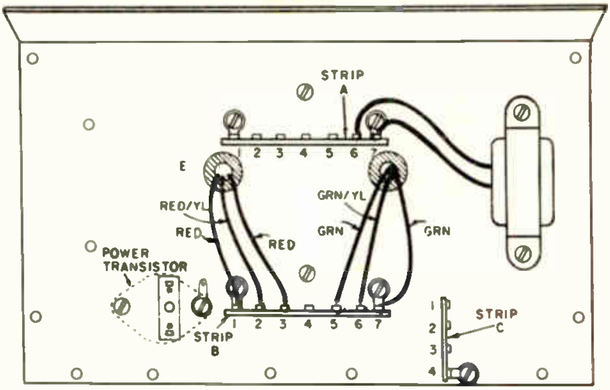


Fig. 13. Preliminary wiring on top of the chassis.

both connections and route the twisted pair along the side of the chassis rail.

Connect one black lead of the power transformer to terminal D1. Solder.

Connect the other black power transformer lead to D3. Do not solder.

Connect one lead of the power cord to D2. Solder.

Connect the other lead of the power cord to D3 and solder.

This completes your preliminary assembly and wiring. Check your work against the diagrams in Figs. 13 and 14 to see that you have done your work correctly.

At this point, your chassis is essentially complete. The space left between the chassis plate and the front rail is reserved for the circuit boards which you will mount and use in your experiments.

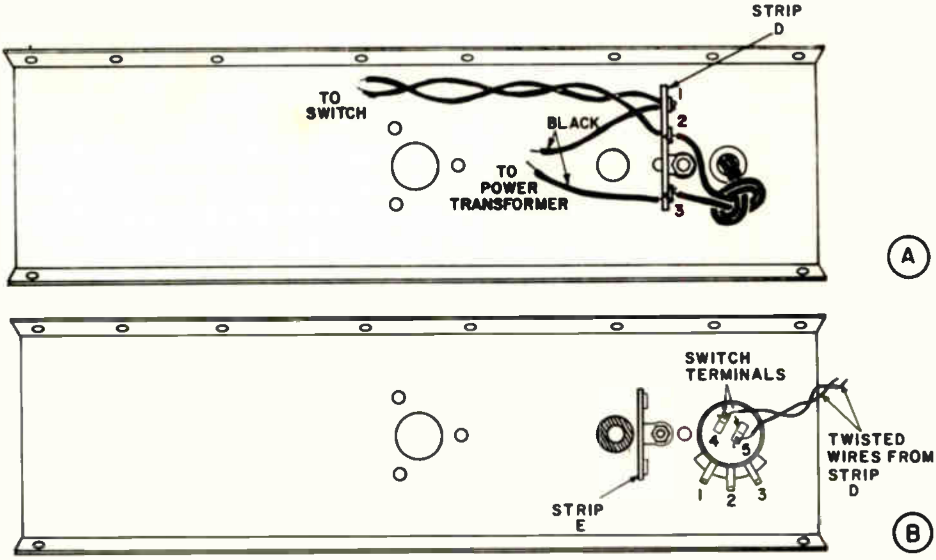


Fig. 14. (A) The wiring inside the left chassis rail. (B) Connections to the on-off switch.

Instructions For Performing The Experiments

Here are some general instructions that you are to follow in performing all of the experiments in this kit and in future ones.

1. Follow these steps for each experiment:

(a) Read the entire experiment, paying particular attention to the discussion.

(b) Perform each step of the experiment, and record your results.

(c) Study the discussion carefully; then analyze your results.

(d) Answer the Statement in the manual and on the Report Sheet.

2. If, when you read through an experiment, you think you won't have enough time to finish it, spend one work period doing any preliminary construction and wiring work. Leave the actual measurements, circuit changes, etc., until you have time to do them all at once.

3. If you do not get acceptable results from any experiment, stop right there and find the trouble before going any further. Do the very best you can to solve the problem yourself, because doing so helps you to develop the troubleshooting techniques you'll need later on. Check over the wiring instructions, test every connection, and test each part if effect-to-cause reasoning fails to lead you to the trouble. Be sure to check the circuit against the schematic. If all these procedures fail, write to us on the special Kit Consultation Blank provided, and tell us which experiment and step you're working on. Give us a complete description of the symptoms that indicate trouble, and list the results of your tests. Go ahead with your regular lessons while waiting for our answer.

4. One object of these practical experiments is to develop your ability to wire a circuit with only a schematic diagram as your guide, just as an experienced serviceman does. Begin now to think in terms of tube and circuit elements rather than specific terminal numbers. For example, instead of thinking of the 100,000-ohm resistor as being between terminals B1 and B3, think of it as being across the high-voltage winding of the power transformer. This will soon teach you to visualize circuits so that you can work from a schematic diagram with ease. Because we want to encourage you to develop this ability, there will be few pictorial sketches in this manual.

5. As in the previous kit, we have omitted the color code listing for the resistors. If you have not yet learned the color code, we urge you to do so immediately. Knowing the code thoroughly is a big time saver in your assembly work, and it helps reduce errors in wiring. If you are in doubt as to the value of a particular resistor, or if you forget the color code, look it up in the chart in your first kit.

6. From now on, we shall not indicate what tools you need to wire circuits. You know that you have to use hookup wire, pliers, screwdrivers, etc. If there is any soldering or unsoldering to be done, you know that you will have to heat your soldering iron and must use rosin-core solder. Therefore, in any experiment in

which you are to make circuit changes, get out the tools you will need, and heat your soldering iron before beginning the assembly or disassembly of that experiment.

EXPERIMENT 31

Purpose: To show that a coil can develop a counter emf and to show that a transformer can be used to step voltage up or down while providing dc isolation.

Introductory Discussion: Coils are among the most widely used electronic components. It is therefore, desirable for you to learn how coils work and how they are used.

The most important characteristic of a coil is inductance. Inductance is the property that causes a magnetic field to be produced around a wire or coil through which current is flowing and causes a voltage to be induced in a wire or coil placed in a varying magnetic field.

Coils may be used separately, where inductance is required, or two or more coils may be wound on the same core to form a transformer. In most cases, transformers are used to inductively transfer signals or ac power from one circuit to another while providing isolation. The voltage may be "stepped" up or down, depending upon the ratio of the turns of the windings and how the transformer windings are connected.

Coils and transformers can be designed to operate at any desired frequency. In this experiment, you will use your power transformer and choke coil which are designed for use in 60-Hz power line applications.

We will use a neon lamp to indicate the presence of voltage in these steps. The tvom is unsuitable for several of these steps because the voltage will rise and fall before the meter has time to respond. The lamp, which you will use, will light when approximately 65 volts is applied to it. Thus, you will know that you have at least that voltage whenever the lamp lights. The brilliance of the glow depends upon the voltage applied to the lamp. Thus it will glow more brightly with 100 volts applied than with 65 volts applied.

Experimental Procedure: For this experiment, you will use the experimental chassis with the choke and the power transformer mounted on it and the following parts:

1 1.5 volt flashlight cell
1 Neon lamp

Make sure the chassis is unplugged from the ac receptacle.

Construct the circuit shown in the schematic diagram in Fig. 31-1. Using temporary connections, connect the neon lamp in parallel with the choke coil between terminals A6 and A7. Solder a 6" to 8" length of hookup wire to each terminal of one flashlight cell. Solder the free end of the negative battery lead to terminal C4 or to any convenient ground terminal.

Step 1: To show that an inductance can develop a counter emf.

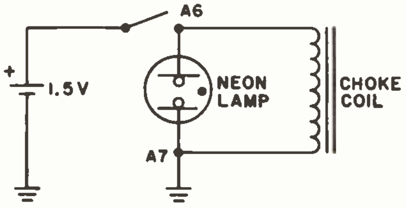


Fig. 31-1. The circuit used in Step 1.

You now have the neon lamp connected in parallel with the choke coil. Touch the positive battery lead to terminal A6. While observing the neon lamp, remove the battery lead from A6 to open the circuit. You should see the lamp flash or glow momentarily. Repeat the experiment. Touch the battery lead to A6 and hold it for a few seconds. Remove the battery lead while observing the bulb.

Now observe the bulb as you *touch* the battery lead to the terminal again. Remove the battery lead. You will find that the lamp lights only as you *open* the circuit.

Now touch the battery lead to the terminal and remove it quickly while observing the lamp. You should find that the length of time the circuit is closed has no noticeable effect on the brilliance of the flash.

Step 2: To show that the transformer windings have inductance and can produce a counter emf.

Connect the neon lamp across the 12.6 volt filament winding of the transformer. Unsolder the lamp from A6 and A7 and solder it to B5 and B7. While observing the neon lamp, touch the positive battery lead to B5. Open the connection and note the brilliance of the lamp flash.

Unsolder the lamp and connect it across the high voltage winding, terminals B1 and B3. Touch the positive battery lead to B3 and observe the lamp. As you open the battery connection, look carefully to see if the lamp flashes. Make and break the connection several times if necessary.

Step 3: To show that a transformer can step up voltage.

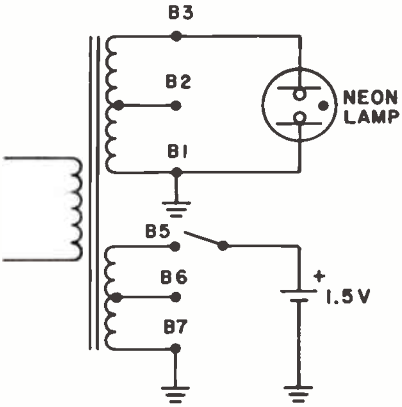


Fig. 31-2. The transformer connected to produce voltage step up.

You will use the circuit shown in Fig. 31-2. Leave the lamp across the high voltage winding of the transformer, but connect the battery across the low voltage winding between terminals B5 and B7.

Touch the battery lead to B5, then break the connection while observing the neon lamp. Note that the flash is the brightest yet obtained in this experiment, indicating the highest voltage.

Step 4: To test the transformer for continuity and isolation.

Set up your tvom for resistance measurements and measure the resistance of the high voltage winding from terminal B1 to terminal B3. The neon lamp will not affect your reading. Record the resistance reading in the chart in Fig. 31-3.

Now connect the ohmmeter across the low voltage winding, terminals B5 and B7 and measure the resistance. Place the value in the space provided in Fig. 31-3.

Next, disconnect the transformer leads from terminals B1 and B7. Make sure that the transformer and battery leads are not shorted to the chassis or to any terminals. Measure the resistance between the leads connected to terminals B3 and B5. Record the value in Fig. 31-3. You should read a very high resistance. When you have made this measurement, reconnect the red lead to B1 and the green lead to B7.

Connect the clip of your tvom to the chassis and the probe to terminal B5. Adjust the meter to read 3 volts dc. Touch the battery lead to the high voltage winding of the transformer at terminal B3.

Allow the meter a couple of seconds to settle down, then observe and jot down the reading in the margin of this page. Remove the tvom probe from terminal B5, then disconnect the positive battery lead from terminal B3.

Discussion: In this experiment, you saw that you were able to light a neon lamp, requiring about 65 volts from a 1-1/2 volt flashlight cell. The inductances of the coil and the transformer windings were responsible for the increase in voltage.

A neon lamp consists of a pair of electrodes placed in neon gas. When a high enough voltage is applied to the electrodes, the neon gas will "ionize" and begin to conduct, thus producing light. The chemical composition of the neon gas and the spacing of the electrodes establishes the voltage required to cause the gas to conduct.

H.V. WINDING	L.V. WINDING	B_3 TO B_5
200Ω	1.5Ω	∞

Fig. 31-3. Chart for recording your transformer resistance readings.

In the first step, the lamp was connected directly across the winding of the choke coil. When the flashlight cell was connected, the coil and the lamp were a parallel-connected load. However, when the battery was disconnected, the coil acted as the source of voltage. It was the voltage produced in the coil that lighted the lamp.

Now, let us review the action of an inductance. Current flowing through a conductor produces a magnetic field around the conductor. This magnetic field will vary in strength as the current in the conductor varies.

A counter emf (or voltage) is produced whenever the current in a coil changes. The amount of the counter emf is governed by the inductance and the rate at which the current changes. When you removed the battery lead from the circuit in Step 1, you caused an instantaneous change in the current from some level of current flow to 0, resulting in a very high counter emf. The fact that the lamp glowed proved that the voltage was 65 volts or more. Thus, the counter emf was at least 43 times as great as the voltage produced by the flashlight cell. Incidentally, the duration of the high voltage was less than one millisecond (1 thousandth of a second).

In Step 2 you saw that transformer windings, like the choke, also have inductance and can produce a large counter emf. Even though there are fewer turns (small inductance) on the low voltage winding than on the high voltage winding, you probably observed a brighter glow when testing the low voltage winding. A look at your readings recorded in Fig. 31-3 will give you a clue as to why you developed a greater counter emf with the low voltage winding. This winding has a very low resistance and thus will draw a large current from the battery to produce a large magnetic field. The much higher resistance of the high voltage winding draws less current and produces a smaller magnetic field than the low voltage winding. Thus, even though the inductance of the HV winding is large, the current is small and a small counter emf is produced.

You obtained the brightest flash when you used the circuit in Fig. 31-2. The lamp was connected across the high voltage winding and you applied voltage to the low voltage winding. The current supplied by the flashlight cell caused a magnetic field to be produced around the low voltage winding. When you opened the battery connection, the field collapsed and a high voltage was induced in the high voltage winding.

In Step 4, you used your tvom to make a few basic tests on the transformer. You read the continuity of the high voltage and low voltage windings and you tested the transformer for isolation.

The low dc resistances proved that the windings have continuity and are capable of passing current. The dc resistance between windings is quite high because there is no direct electrical connection between them. Also, you saw that there was no transfer of the dc voltage through the transformer. Only alternating or changing voltages are coupled from one winding to another.

Instructions for Statement No. 31: For this Report Statement, you will determine if a short circuit in one winding of a transformer affects the voltage induced in another winding.

Make sure the line cord is unplugged. The circuit of Fig. 31-2 should still be connected. Touch the battery lead to terminal B5 and quickly remove it. Make a mental note of the brilliance of the flash of the neon lamp across the high voltage winding.

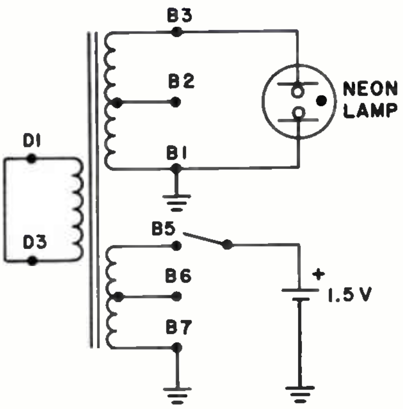


Fig. 31-4. The schematic diagram of the circuit used for Statement 31.

Next, place a short circuit across the transformer primary winding. Turn the on-off switch "on" and hold both prongs of the power cord against the metal chassis. This will give you the circuit shown in the schematic diagram in Fig. 31-4. Note that you are now using all three windings of the transformer, with the low voltage winding acting as the primary.

Touch the battery lead to terminal B5 and open the connection while observing the neon lamp.

Answer the Statement here and on the Report Sheet. Unsolder and remove the neon lamp and the flashlight cell from the chassis.

Statement No. 31: When I placed a short circuit across the transformer primary winding, I found that the voltage induced in the high voltage winding was

(1) higher.
(2) unchanged.
[✓ *(3) lower.*]

Assembling A Basic Power Supply

Before going further you will mount your etched circuit board and several other parts on your chassis and wire a simple power supply circuit. You will use the 7 pin tube socket on the circuit board and make connections to the circuit board and to the terminal strips on the chassis. You will also wire the neon lamp into the circuit so that it will show you when the circuit is energized.

Gather the parts listed below from the parts sent you with this kit and from those left over from the other kits.

1	**Etched circuit board**
1	**12BA6 tube**
9	**1/4" X 4-40 screws**
9	**4-40 hex nuts**
5	**Terminal lugs**
2	**100K-ohm resistors**
1	**Neon lamp**

First, attach the 5 terminal lugs to the circuit board at the locations shown in Fig. 15. Use 1/4" X 4-40 screws and 4-40 nuts. Position the lugs as shown, so they do not touch adjacent copper strips or terminals.

Mount the circuit board in the location shown in Fig. 15 with four 1/4" X 4-40 screws and nuts. Note that the tube socket is towards the chassis plate and the circuit board is near the center of the opening in the chassis.

Next, you will wire the circuit shown in the schematic in Fig. 16. The terminal lugs on the circuit board are numbered 1 through 5, as shown in Fig. 15. The broken line in Fig. 16 encloses the wiring on the etched circuit board itself. Note on the circuit board that the copper foil connects pins 2, 5 and 6 of the tube socket and lug 5. Pin 1 of the tube socket is connected to lug 3 and pins 3, 4 and 7 are connected to lugs 2, 1 and 4, respectively.

You can use the diagram in Fig. 15 for help in wiring the circuit shown in the schematic.

Note that lengths of hookup wire are connected from lug 3 to lug 5 on the circuit board and between terminals B2 and A2. The green lead and green/yellow lead of the power transformer, connected to terminals B6 and B7, are interchanged from their previous positions as are the red and red/yellow leads connected to terminals B1 and B2. The neon bulb is connected to A2 and A3 and a 100K-ohm resistor is connected from A3 to B3.

When you complete your wiring, check over your work and insert the 12BA6 tube in the socket.

Radio-TV parts may look perfectly all right and yet be defective. An important part of every assembly procedure is to make resistance tests to be sure that there are no shorts or opens. If the results of these tests are satisfactory, then it is safe to apply power and make voltage measurements.

CONTINUITY TESTS

For a power supply like the one you have wired, you should check the continuity of the circuits and be on the

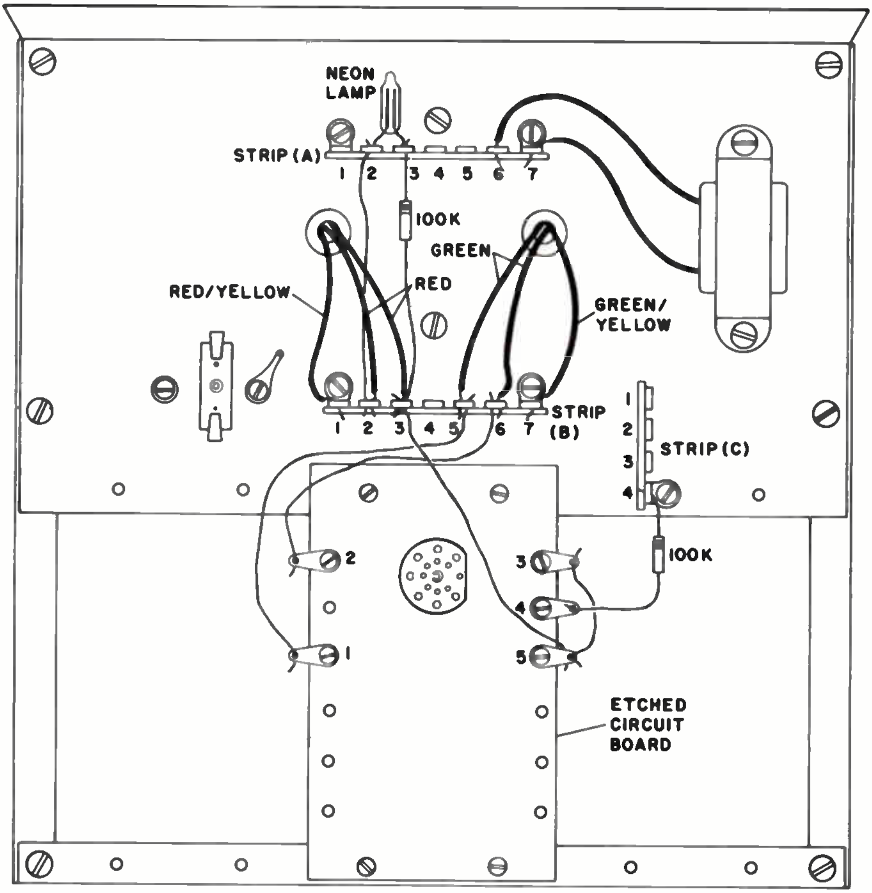


Fig. 15. Pictorial diagram of the power supply wiring.

lookout for a short between the cathode terminal of the rectifier tube and the chassis. A short of this type could not only ruin the tube, but it could also damage the power transformer.

You will use the ohmmeter section of your tvom to carry out the continuity tests. Turn your tvom on and turn the function switch to ohms. Do not plug in the line cord of your chassis until you are instructed to do so.

First, turn off the switch on the power supply: Turn the knob on the 500K-ohm potentiometer shaft all the way in the counterclockwise direction until you hear a click. With the switch in the off position, proceed with the continuity tests.

To test the line cord, switch, and primary transformer winding, turn the range switch to the R X 10K position, and connect the ohmmeter leads to the prongs of the power cord plug. You should get no reading on the ohmmeter, indicating that no continuity exists in the circuit. Now with the ohmmeter test probes still connected to the prongs, turn the power supply switch on. Immediately the meter pointer should move to the zero position. Turn the range switch to the R X 1 position. When you do this, the meter should indicate between 20 and 40 ohms, which is the resistance of the primary power transformer winding.

Next, connect your ohmmeter leads to lugs 1 and 2 of the circuit board. These lugs connect to pins 3 and 4 of the tube socket. You should measure about 1 ohm. This is the parallel resistance of the filament winding and the 12BA6 heater.

To check half of the high voltage winding of the power transformer, connect the ground clip to the chassis and touch the probe to lug 5. With the range switch in the R X 1 or R X 10 position, your reading should be approximately 80 ohms.

Next, measure the resistance from tube cathode (lug 4) to the chassis. Here you should get a reading of approximately 100,000 ohms, measured on the R X 10K ohmmeter range. A very low reading indicates a short. Look for solder that may have dripped down and shorted to the chassis, or for improper wiring.

VOLTAGE TESTS

If the results of the continuity tests are satisfactory, you can now check the voltages of the power supply. Plug the supply into a 117-volt, 60-Hz receptacle. The on-off switch is still in the on position. Set your voltmeter up for ac measurements, and turn the range switch to the 120-volt position. Measure the voltage between the chassis and lug 5 of the circuit board. Since you are measuring half of the high voltage winding of the power transformer, you should get a reading of approximately 65 volts.

Now set the range switch to the 30-volt position and measure the voltage between lugs 1 and 2 of the circuit board. You should get a reading between 12 and 13 volts.

To measure the line voltage, remove the line cord plug from the wall outlet, turn your chassis up on its back edge and connect the ground clip of your tvom to terminal D3. Turn the tvom range switch to the 300-volt range, and plug the line cord back into the wall outlet. Touch the tvom probe to terminal D2. You will get a reading of approximately 117 volts. The actual voltage in your area may be any value from 105 volts to 130 volts. Unplug the power cord and disconnect the meter ground clip.

When you have finished making these measurements and found that the continuity and the ac voltages of the power

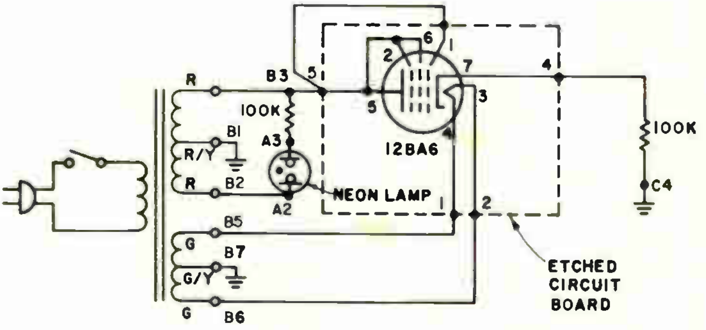


Fig. 16. The basic power supply circuit.

supply are correct, you are ready to go ahead with the next group of experiments. If any readings were not correct, be sure to find out what is wrong before proceeding with the experiments. If you need help, write us, giving the results of all your measurements.

EXPERIMENT 32

Purpose: To show that when an ac voltage is applied to a rectifier and a resistor in series, a dc voltage will be produced across the resistor; and to show that the polarity of the voltage drop across the resistor depends on how the rectifier is connected into the circuit.

Introductory Discussion: The circuit you will use to show that there is a dc voltage across the load when an ac voltage source, a rectifier, and a load (in this instance a 100,000-ohm resistor) are connected in series is shown in Fig. 32-1. This is the half-wave rectifier circuit that you built and tested earlier. To simplify the discussion, we will consider the power transformer to be the ac source. Actually, of course, power is drawn from the power line to excite the primary winding of the power transformer.

To show that the voltage drop across the 100,000-ohm load resistor is a dc voltage, you will make use of the fact that under ordinary conditions your tvom will not respond to any ac voltage when the function switch is in the dc position. You will use the normal-reverse switch to indicate polarity. When the meter pointer deflects to the right (upscale), the polarity of the voltage at the terminal to which the probe is being touched is positive if the polarity switch is set to normal, and negative if the switch is in the reverse position.

We usually use diode tubes as tube-type rectifiers. As you know, a diode tube has two elements called a cathode and a plate (in addition to the heater). You will use your 12BA6 tube, which is a pentode, as a diode. By connecting the three grids to the plate externally, as shown in Fig. 32-1, we make the pentode act as a diode.

Experimental Procedure: For this experiment, in addition to the power supply circuit you have constructed, you will need:

1 HV silicon diode

Turn the tvom on and clip the ground lead to the experimental chassis. This is the same as clipping it to the 100,000-ohm resistor lead that goes to terminal C4 since C4 is grounded. Set the function switch to the dc position, the slide switch to normal, and the range

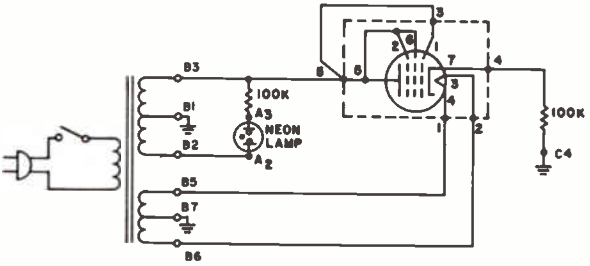


Fig. 32-1. The half-wave rectifier circuit used in Step 1.

STEP	READING
1	28.5V
3	28.5V
4	-23V

Fig. 32-2. Chart for recording your voltage readings for Experiment 32.

switch to the 120V position. You are now ready to proceed with the first step.

Step 1: To show that there is a dc voltage across the load resistor in series with a diode tube rectifier and an ac source.

Insert the plug of the power cord into an ac receptacle, and turn on the on-off switch. Allow the tube to warm up and touch the probe of your tvom to the end of the 100,000-ohm resistor that is connected to lug 4 of the circuit board. If you read less than about 25 volts, adjust the range switch to the 30V range, measure the voltage and record your reading in the first line of the table in Fig. 32-2. Turn your circuit off.

Step 2: To show forward and back resistance of a diode.

7Ω

Set the function switch of your tvom to ohms on the R X 1 range and clip the ground lead to the cathode lead of the silicon diode. Touch the probe to the anode lead and measure the resistance. (The leads are identified by a diode symbol on the body of the diode.) Be sure the meter is set to normal. You should read a low resistance. Record your reading on the first line in Fig. 32-3.

Reverse the tvom leads by placing the normal-reverse switch in the reverse position and again measure the resistance between the cathode and anode leads of the diode. Switch the ohmmeter to a higher range, if necessary, to get a reading. Record your value in the space provided in Fig. 32-3.

Step 3: To show that a silicon rectifier gives essentially the same results as a vacuum tube rectifier.

Remove the 12BA6 tube from the tube socket on the circuit board. Grasp the tube with a cloth if it is still hot. Connect and solder the silicon rectifier between lugs 4 and 5 on the circuit board as follows: Connect the cathode lead to lug 4 and connect the anode lead to lug 5.

Set your tvom to read positive dc voltage on the 120-volt range and clip the ground lead to the chassis. Turn the circuit on and measure the voltage across the 100K-ohm load resistor. Record your reading in the space provided for Step 3 in Fig. 32-2.

Step 4: To show that the polarity of the voltage across the load resistor depends on how the rectifier is connected in the circuit.

Set up the circuit shown in Fig. 32-4, in which the anode and cathode connections are the reverse of those in the circuit you just used. Interchange the diode leads: Connect the cathode lead to

DIRECTION	RESISTANCE
FORWARD	7.Ω
REVERSE	3. Mega

Fig. 32-3. Chart for recording rectifier resistance values.

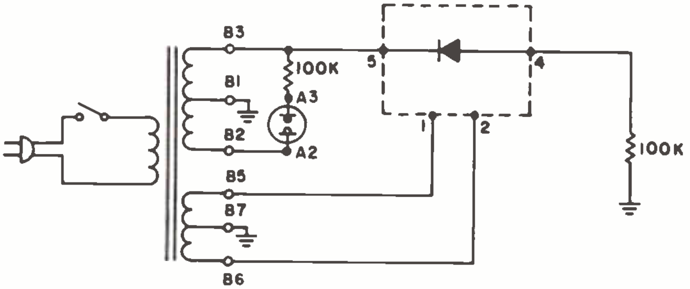


Fig. 32-4. The circuit used for Step 4.

lug 5 of the circuit board and connect the anode lead to lug 4.

To show that the polarity of the voltage drop across the load resistor has changed, turn on the experimental chassis, connect the ground clip of the tvom to the chassis, and momentarily touch the probe to lug 4. Note that with the slide switch in the normal position, you get a downscale reading.

Move the slide switch on the tvom to reverse and touch lug 4. Now you should get an upscale reading. This indicates that the point to which the probe is touched is negative with respect to the point to which the ground lead is connected. The reading you get should be just about the same as the one you got in Step 3, since the only difference between the circuits is that the connections to the rectifier are reversed. Record your reading on the third line of Fig. 32-2 as a minus (–) value, and turn off the power supply.

Unsolder and remove the silicon diode from the circuit board.

Discussion: The fact that a direct current flows through the load in the circuits you have set up is based on a fundamental property of a rectifier -- current will flow more easily through a rectifier in one direction than in the other.

In Step 2, you used your ohmmeter to show that the effective resistance of a diode depends upon the polarity of the voltage applied to it. When the plate or anode is *positive* with respect to the cathode, the resistance is low; when the anode or plate is *negative* with respect to the cathode, the resistance is high.

Your ohmmeter is wired so that with the polarity switch set to normal, the probe is slightly positive with respect to the ground clip. Thus, when the probe was connected to the anode and the ground clip was connected to the cathode, the diode conducted readily and you measured a low value of resistance. When you reversed your ohmmeter leads, you reversed the polarity of the voltage applied to the diode, and the effective resistance of the diode became quite high.

The tube-type rectifier has similar characteristics. When the plate is positive with respect to the cathode, the effective resistance between cathode and plate is low; when the applied voltage is reversed, the effective resistance is very high.

This is a good way of checking most solid-state diodes. Measure the resistance in both directions and compare your results. In one direction, you should have a high resistance and in the other, you should obtain a low resistance. Certain special purpose diodes, such as high voltage selenium types used in color TV sets, cannot be tested in this manner as they show a high resistance in both directions.

In each of the circuits you set up in this experiment, the plate or anode is alternately positive and negative during each ac cycle and current flows through the rectifier and load as a series of pulses. Since the voltage drop across the load is in direct proportion to the current flowing through it, the load voltage is also a series of pulses. If you were to connect a cathode ray oscilloscope across the load, you would get a pattern somewhat like that shown in Fig. 32-5.

As you can see, each voltage pulse extends in the same direction from the zero reference line. Therefore, the series of pulses contains a dc component that we can measure.

The rectifier circuit you used is known as a half-wave rectifier because it passes current during only half of the ac cycle. When there is no filter capacitor in the circuit (the effect of a filter will be shown later), the dc component that the meter indicates is much less than the peak value of the voltage pulses. The pulses reach a peak nearly equal to the peak value of the ac source voltage, but the tvom is capable of measuring only the average of the positive pulses, which is about one-third of the peak value.

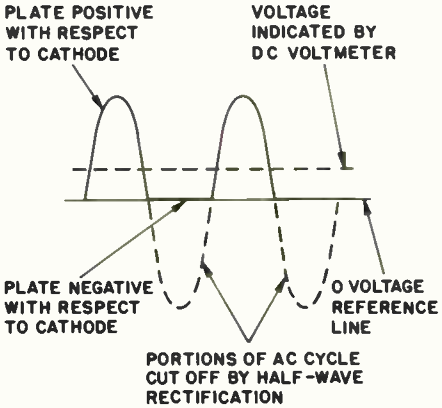


Fig. 32-5. The heavy line indicates the shape of the voltage across the load of the half-wave rectifier circuit.

Some important radio and TV servicing principles are shown by this experiment. First, as you know, you must set the polarity switch of your tvom to the proper polarity to make the instrument indicate dc voltages correctly. By the term "proper polarity" we mean that the polarity switch must be set so that the meter pointer moves to the right when you make a voltage measurement. If the meter pointer moves to the left, the switch must be moved to the opposite position.

In any device in a circuit, except the source, the terminal at which the electrons enter is the negative terminal. This fact lets you find the direction of the electron flow by examining the diagram. If there are tubes in the circuit, electrons always flow from the cathode to the plate, and this establishes the direction of electron flow through any parts in series with the tubes. Knowing the direction of electron flow, you can determine the polarity of the voltage drops across the parts.

Instructions for Statement No. 32: For your Report on this experiment, you will put the load between the plate of the rectifier tube and the ungrounded side of the high voltage winding. The circuit is shown in Fig. 32-6. You are to measure the dc voltage drop across the load, and compare it to the voltage drops you measured in Steps 1 and 3 of the experiment.

To change the circuit, proceed as follows: First, unsolder and remove the 100K-ohm resistor which is connected

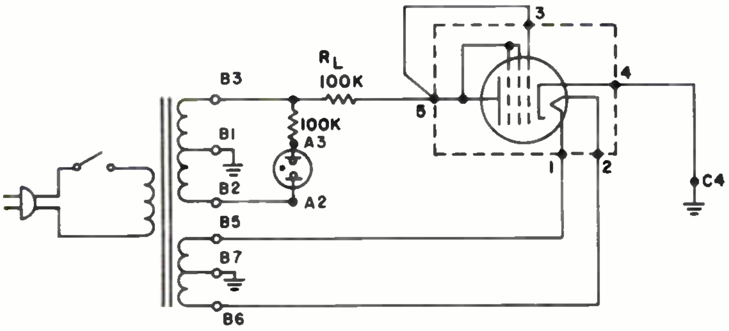


Fig. 32-6. The circuit for Statement 32.

from the circuit board to terminal C4. Unsolder and remove the length of hookup wire connecting terminal B3 to the circuit board.

Connect a length of hookup wire from lug 4 of the circuit board to terminal C4.

Connect the 100,000-ohm resistor between terminal B3 and lug 3 or 5. Solder all connections and insert the tube in the socket. Your circuit should now be like Fig. 32-6.

Connect the ground clip of your tvom to lug 5, plug the power cord into the ac outlet, and turn the circuit on. Carefully consider the direction of electron flow through the load resistor, and set your polarity switch to give an upscale reading when you touch the probe of your tvom to terminal B3. Make a note of your reading, then turn the circuit off. You now have sufficient information to complete the Statement.

Statement No. 32: When I measured the dc voltage across the 100,000-ohm resistor, I found that it was:

(1) much lower than
(2) considerably higher than
[✓ *(3) essentially the same as*]

the dc voltage I measured in Steps 1 and 3.

EXPERIMENT 33

Purpose: To demonstrate the basic operation of the full-wave rectifier circuit and to show that it has better regulation than the half-wave rectifier circuit.

Introductory Discussion: A half-wave rectifier circuit has a diode connected between the ac source and the load so that current passes to the load only once during each cycle. In a full-wave rectifier circuit, two diodes are connected in such a manner that one diode conducts on each half of the ac cycle. Thus, both the negative and positive halves of the ac voltage are used and current passes to the load twice during each cycle. Because of this, the full-wave rectifier can supply greater current than can a half-wave rectifier under similar circumstances and it is better able to supply a constant voltage to varying load resistances.

Experimental Procedure: For this experiment, you will need your chassis, your tvom and the following parts:

1 HV silicon diode
1 22K-ohm resistor
1 .25-mfd capacitor

Before you begin the experiment, construct the circuit shown in the schematic diagram in Fig. 33-1. First, unsolder and remove the 100,000-ohm resistor connected from terminal B3 to the circuit board and replace it with a short length of hookup wire. Then remove the wire connected between terminal C4 and lug 4 on the circuit board and connect the 100,000-ohm resistor in its place.

Connect the HV diode between terminals B2 and B4 with the cathode lead to B4 and connect a length of hookup wire from B4 to lug 4 on the circuit board.

Check over your wiring and make sure all connections are soldered.

Step 1: To demonstrate the operation of the full-wave rectifier circuit.

Turn the circuit on, allow the tube time to warm up, and measure the voltage across the 100K-ohm load resistor. Set the tvom to measure dc voltage on the 120-volt range, clip the ground lead to the chassis and touch the probe to lug 4. Read the meter and record the value in the chart in Fig. 33-2. Switch your tvom 60V to ac and measure the voltage from terminal B3 to the chassis. Move the probe to terminal B2 and note that you read the same voltage. You should have approximately 65 volts at both terminals.

64V Turn the chassis off and unsolder the resistor lead from lug 4 of the circuit board. Connect a .25-mfd capacitor from lug 4 to terminal C4.

Step 2: To show that the full-wave rectifier will charge a capacitor to the peak value of the applied voltage.

Set the function switch of the tvom to the dc position, turn the circuit on and allow time for warm-up. Touch the probe to lug 4 and measure the voltage across the .25-mfd capacitor. Note that it is 92V much higher than the voltage across the resistor alone. Record the voltage in the space provided for Step 2 in Fig. 33-2. Turn the circuit off.

Discharge the capacitor by shorting across its leads or by grounding lug 4 to the chassis momentarily. Connect the 100K-ohm resistor in parallel with the .25-mfd capacitor by connecting the free resistor lead to lug 4 of the circuit board.

Step 3: To measure the voltage developed across a load resistor shunted by a capacitor.

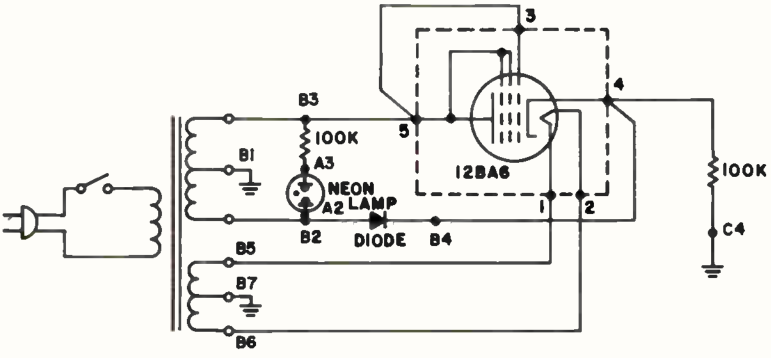


Fig. 33-1. Full-wave rectifier circuit for Experiment 34.

STEP	CIRCUIT	VALUE
1	100K Load Resistor	60V
2	.25-MFD Capacitor	92V
3	100K Resistor Shunted by .25-MFD Capacitor	82V
4	22K Resistor Shunted by .25-MFD Capacitor	67V
5	Half Wave With 22K Resistor and .25-MFD Capacitor	46V

Fig. 33-2. The chart used with this experiment.

Turn the circuit on, allow time for the tube to warm up and measure the voltage across the load. Record your voltage reading in the space for Step 3 in Fig. 33-2. Turn the circuit off and replace the 84 100K-ohm resistor with a 22K-ohm resistor.

Step 4: To measure the output of the full-wave rectifier with a heavier load connected across it.

Turn the circuit on and measure the voltage between lug 4 of the circuit board and the chassis. Note that it is lower than the voltage you measured in the preceding step. Record the voltage in the chart in Fig. 33-2.

Step 5: To show that the full-wave rectifier circuit has better voltage regulation than the half-wave rectifier.

Remove the 12BA6 tube from the socket and turn the circuit on. Without the tube, you have a half-wave rectifier, using only one-half of the transformer winding and the silicon diode. Measure the voltage across the 22K-ohm resistor and the capacitor and place your reading in the chart in Fig. 33-2. Turn the circuit off.

Discussion: The full-wave rectifier circuit is essentially two half-wave rectifiers arranged so they operate alternately and supply current to the same load.

The fundamentals of full-wave rectification are shown in Fig. 33-3. The transformer winding is center-tapped and the center tap is our point of reference. With respect to the center tap, the ends of the

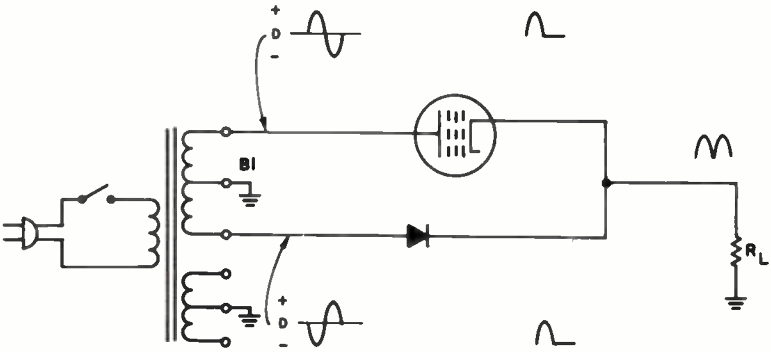


Fig. 33-3. Diagram showing the waveform in the full-wave rectifier circuit used in Step 1.

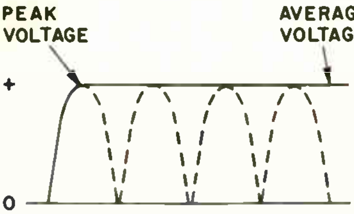


Fig. 33-4. Voltage across the capacitor in Step 2.

transformer winding are 180° out-of-phase with each other. Thus, during one half-cycle of the ac, the plate of the tube is positive, and the anode of the silicon diode is negative; during the next half cycle, the plate of the tube becomes negative and the anode of the diode becomes positive.

As you know, a diode conducts only when its plate or anode is positive with respect to its cathode. Therefore, the tube conducts and passes current through the load on one half-cycle and the silicon diode conducts and passes current on the other half-cycle. Thus, the spaces between the pulses produced by a half-wave rectifier circuit are filled in, as there are two pulses produced during each cycle.

Note that with full-wave rectification, there is always some positive voltage across the load. Therefore, the average voltage is higher. For this reason, you measured about 60 volts across the resistor in Step 1. You may remember that in the preceding experiment, you read only about 30 volts across the resistor in the half-wave rectifier circuit.

In Step 2, you should have found that the capacitor charged to approximately 90 volts, which is the peak value of the ac voltage. The peak value of a sine wave is equal to 1.4 times the rms voltage. Fig. 33-4 shows the waveform of the voltage across the capacitor. Note that the spaces between the pulses are filled in so that the average voltage is equal to the peak voltage.

When you connected the capacitor and 100K-ohm resistor in parallel across the output of the full-wave rectifier, you should have noticed some reduction in the dc output voltage. The capacitor charged each time the diode conducted and discharged through the resistor each time the rectifier output voltage passed its peak value. The waveform of the voltage across the resistor and capacitor is shown in Fig. 33-5. The effect of the capacitor was to produce a higher average voltage.

In Step 4, you increased the load on the rectifier circuit. You should have measured about 70 volts across the load. This voltage is lower than that measured in Step 3 because the capacitor discharges more quickly through the lower load resistance. As a result, the average voltage falls to a level nearer to that which you would have measured with no capacitance in the circuit.

The half-wave rectifier output voltage was much lower with the low load resistance. This is due to the fact that in the half-wave circuit, no voltage is supplied by the rectifier for a large percentage of the time. Thus, the capacitor is able to discharge almost completely between pulses as shown by the waveform in Fig. 33-6. In these last two steps, you can see

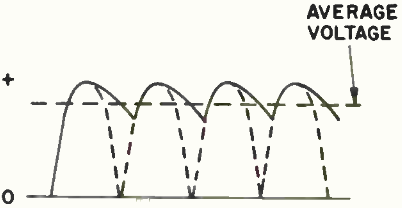


Fig. 33-5. Voltage across the capacitor and resistor in Step 3.

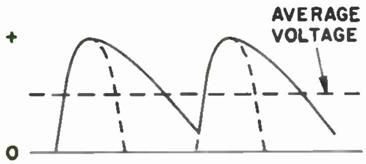


Fig. 33-6. Waveform across the capacitor and resistor in Step 5.

that the full-wave rectifier circuit has better regulation than the half-wave rectifier. Although both circuits develop about 90 volts across the capacitor alone, when a 22K resistor was connected across the capacitor, the output voltage of the full-wave rectifier fell to about 70 volts while the output of the half-wave rectifier was reduced to about 45 volts.

Instructions for Statement No. 33: For this Report Statement, you will disconnect the center tap of the transformer from the grounded terminal and measure the voltage across the load. Unsolder and disconnect the red/yellow lead from terminal B1 and push it out of the way. Put the tube back in the socket.

Turn the circuit on, measure the voltage between the chassis and lug 4 on the circuit board and answer the Statement here and on the Report Sheet. Turn your circuit off.

Statement No. 33: When I disconnected the transformer center tap lead, the voltage across the load:

[✓ *(1) decreased to zero.*]
(2) increased slightly.
(3) decreased slightly.

EXPERIMENT 34

Purpose: To demonstrate the basic operation of the bridge rectifier circuit and to show the effects of loading the circuit.

Introductory Discussion: In the previous experiments, you studied some of the characteristics of simple half-wave and full-wave power supplies. Now, you will take up the full-wave bridge rectifier circuit.

Full-wave bridge rectifier circuits are used in both high and low power applications. They are often used in the ac voltmeter sections of multimeters. The ac voltage applied to the input section of the meter is rectified by the bridge circuit and the resulting dc voltage is applied to the meter circuit. Full-wave bridge rectifier circuits using solid state diodes are found in power supplies in many TV receivers and transmitters.

The diagram in Fig. 34-1 shows how a full-wave bridge circuit works. The semiconductor diodes are labeled W, X, Y and Z. The ac voltage is fed to the bridge circuit at points A and D, and the load, represented by resistance R_L, is connected between points B and C.

The arrows indicate the directions of current flow. When point A is negative, with respect to point D, the current shown by the solid arrows flows from

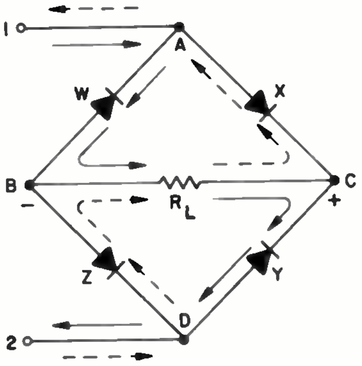


Fig. 34-1. Basic bridge rectifier circuit.

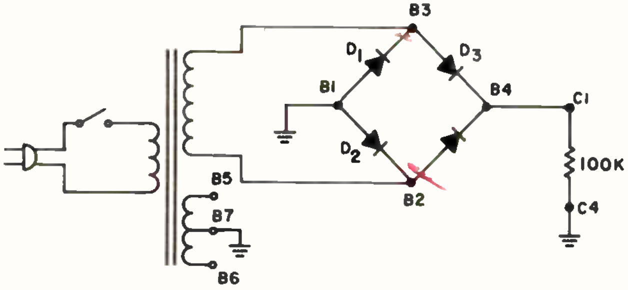


Fig. 34-2. Schematic diagram of the bridge rectifier circuit for Step 1.

point A through rectifier W, through R_L from left to right, and through rectifier Y to point D.

On the next half-cycle when point D is negative with respect to point A, the current flows as shown by the arrows drawn with broken lines. The current flows from point D through rectifier Z through the load resistor from left to right, and through rectifier X to point A.

Notice that the current flows through R_L in the same direction on both half-cycles of the applied ac voltage. Thus, point B is negative and point C is positive in the circuit in Fig. 34-1.

Experimental Procedure: For this experiment, you will need the following parts in addition to the chassis and tvom:

2 LV silicon diodes
1 HV silicon diode
1 .25-mfd capacitor

Construct the bridge rectifier circuit shown in the schematic diagram in Fig. 34-2. The wiring is shown in the pictorial diagram in Fig. 34-3. You should already have the red/yellow transformer lead disconnected from terminal B1. Also, there should be a HV silicon diode connected between terminals B2 and B4. The other HV diode is D_3. Use the LV diodes at D_1 and D_2.

When you have the circuit wired, be sure to remove the vacuum tube and then check your wiring to be sure there are no short circuits and that all connections are correct and soldered.

Step 1: To show that the bridge rectifier is a full-wave rectifier circuit and that a low dc voltage exists across each diode.

Set your tvom to measure positive 300 volts dc and clip the ground lead to the chassis. Turn the circuit on and measure the voltage across the 100K-ohm load resistor. You should read about 120 volts dc. Place your voltage reading in the chart in Fig. 34-4. 115

Touch the probe to terminal B2 and
55v measure the dc voltage across diode D_2.
55v Move the probe to terminal B3 and
measure the dc voltage across diode D_1. Note that the two voltage readings are about the same. Jot down the voltage readings in the margin of this page.

Turn the circuit off and replace the 100K-ohm resistor with a .25-mfd capacitor. You may disconnect the resistor lead from terminal C1 and leave the other lead connected to terminal C4. Solder the capacitor leads to terminals C1 and C4.

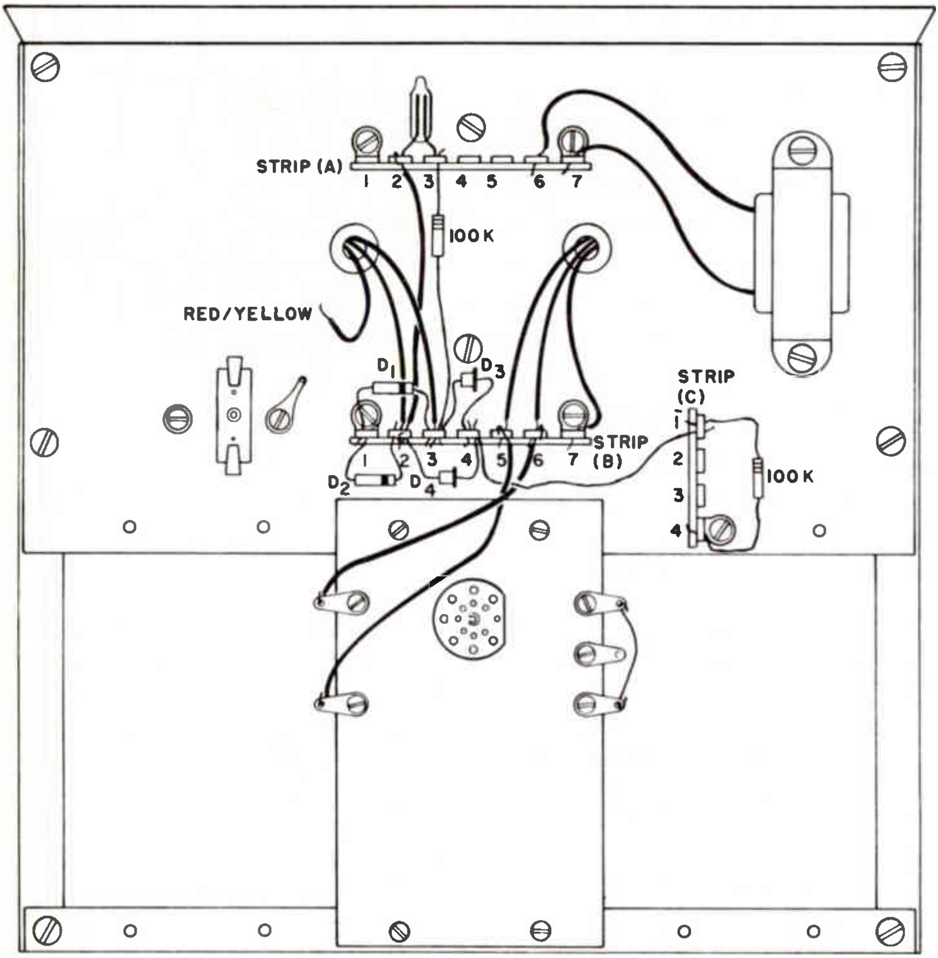


Fig. 34-3. Pictorial diagram of the circuit in Fig. 34-2.

Step 2: To show that the bridge rectifier will charge a capacitor to the peak value of the ac voltage.

Turn the circuit on and measure the voltage across the capacitor. Record the voltage in the space for Step 2 in the chart in Fig. 34-4. Turn the circuit off.

180V

Step 3: To show that the bridge rectifier will supply dc to a load shunted by a capacitor.

Connect the 100K-ohm resistor in parallel with the .25-mfd capacitor. Turn the circuit on and measure and record the voltage across the resistor and capacitor in the chart in Fig. 34-4. 160

Turn the circuit off and unsolder the resistor lead from terminal C1. Also, unsolder the lead of the LV diode, D_1, from terminal B3 and unsolder the lead of the HV diode, D_4, from terminal B2.

Step 4: To show that the bridge

rectifier can operate as a half-wave rectifier.

Energize the circuit and measure the voltage across the .25-mfd capacitor. It should read about the same as the voltage in Step 2. Record the voltage in the space for Step 4 in Fig. 34-4 and turn the circuit off. 180

Discussion: In this experiment, you operated your circuit from the full high voltage secondary winding of your transformer. Thus, the applied ac voltage was about 130 volts. This has a peak value of 130 X 1.4 or about 180 volts.

The dc voltage across the load resistor in Step 1 was about 120 volts. From previous discussions you know that this is the average value of the pulses which rise from zero to the peak voltage. The average value is about two-thirds of the peak value. Thus, you can be reasonably sure that the circuit is a full-wave rectifier, producing two positive pulses across the load during each cycle. The waveform of the output voltage is shown in Fig. 34-5A.

The rectifier circuit charged the .25-mfd capacitor to the peak value of the ac in Step 2. You should have measured about 180 volts, which is approximately the peak value of 130 volts ac.

STEP	VOLTAGE
1	115 ✓
2	180 ✓
3	160 ✓
4	180V

Fig. 34-4. Chart for use with Experiment 34.

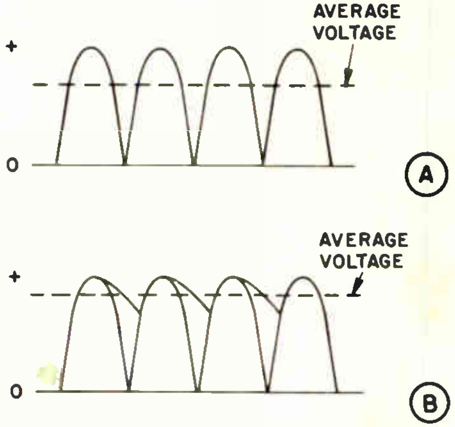


Fig. 34-5. Waveforms of voltages across (A) load resistor only in Step 1 and (B) load resistor and capacitor in Step 3.

In Step 3, you had a 100K-ohm load resistor shunted by a .25-mfd capacitor. You should have measured about 165 volts across the 100K-ohm load resistor and the capacitor. This is about an 8% drop from the voltage across the capacitor alone, and about a 40% increase over the voltage across the resistor alone. As in the previous experiment, the average voltage is higher than it was without the capacitor because the capacitor charges fully on each peak and discharges into the load between peaks producing the waveform shown in Fig. 34-5B.

You converted your bridge rectifier to a half-wave rectifier in Step 4 by disconnecting two of the diodes. A schematic diagram of the circuit used in Step 4 is shown in Fig. 34-6. The circuit should have charged the capacitor to the peak voltage of about 180 volts.

Refer to the schematic. Note that the two diodes are connected so that they pass current in the same direction and at the same time. When the polarity of the ac voltage is such that terminal B3 is

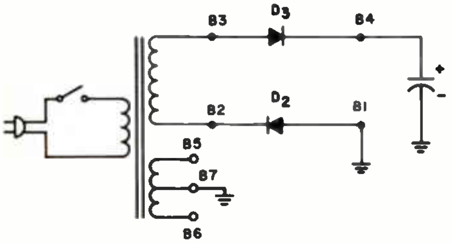


Fig. 34-6. Schematic diagram of the bridge circuit used as a half-wave rectifier.

positive with respect to terminal B2, current flows from B2 through diode D_2 to terminal B1 and ground. From ground, the current flows up to the negative plate of the capacitor. From the positive capacitor plate, current flows through diode D_3 and back to the transformer at terminal B3. On the other half-cycle of the ac voltage, the diodes do not conduct and no current flows.

Instructions for Statement No. 34: For this statement you will compare the operation of the circuit used in Step 4 with a circuit having three diodes.

Connect the 100K-ohm resistor in parallel with the .25-mfd capacitor. Turn the circuit on and measure the dc voltage across the capacitor and resistor. Jot down the value in the margin and turn the circuit off. 150V

Resolder the lead of the HV diode, D_4, to terminal B2 to form the circuit shown in the schematic in Fig. 34-7. Energize the circuit and measure the voltage across the resistor and capacitor again. Compare the results of the two tests and answer the Statement here and on the Report Sheet. Turn the circuit off. Unsolder and remove the two LV diodes and resolder the red/yellow transformer lead to terminal B1.

150V

Statement No. 34: When I connected diode D_4 into the circuit I found that the voltage across the load:

(1) increased by more than one-half.
(2) increased by about one-third.
[✓ *(3)*] *remained the same.*

This proves that with three diodes, the circuit acted as a:

[✓ *(1)*] *half-wave rectifier circuit.*
(2) full-wave rectifier circuit.
(3) full-wave bridge rectifier circuit.

EXPERIMENT 35

Purpose: To show that there is a ripple voltage at the rectifier output; to show that 120 Hz ripple can be filtered more easily than 60 Hz ripple; and to show that this ripple can be filtered out with a choke and a capacitor.

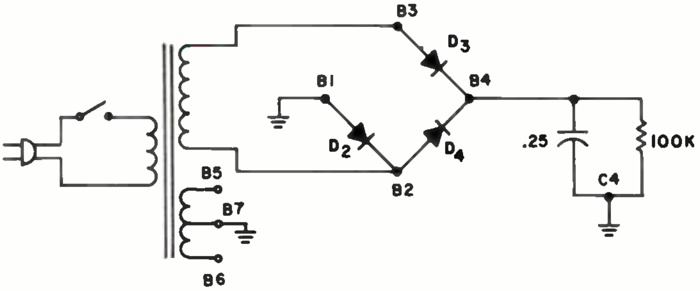


Fig. 34-7. The circuit used for Statement 34.

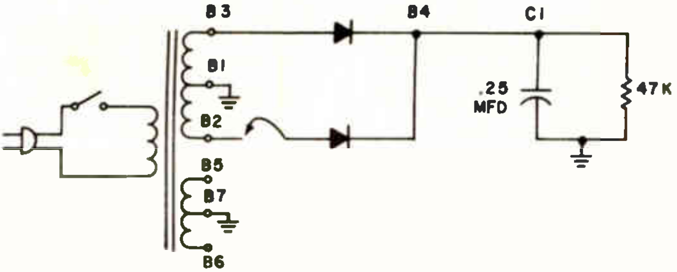


Fig. 35-1. The circuit used in Step 1.

Introductory Discussion: So far we have considered only the pure dc voltage across the load. However, if you connect an ac voltmeter across the load, you will find that there is also an ac voltage. This voltage is the ac component of the pulsating dc output of the rectifier. That is, it is not an ac voltage in the sense that its polarity is alternately positive and negative with respect to the zero reference level, but it is a rise and fall in the dc voltage value. For all practical purposes, however, it acts like any other ac voltage.

A capacitor connected across the load will have a definite effect on this ac component. In this experiment you will measure the ripple voltage and see how it can be reduced to a very small value so that almost pure dc can be supplied to the load.

Experimental Procedure: In addition to your tvom and the parts mounted on your chassis, you will need the following parts:

- 2 20-mfd, 150V electrolytic capacitors
- 1 47K-ohm resistor

Heat your soldering iron and carefully examine the tip. Clean and re-tin it if necessary. Also, check the calibration of your tvom.

The circuit which you will use in this experiment is shown in Fig. 35-1. You will only have to unsolder the anode lead of the diode from terminal B2 and replace the 100K-ohm resistor with a 47K-ohm resistor.

Step 1: To measure the ac ripple voltage and the dc voltage produced by a half-wave rectifier across the 47K-ohm load shunted by a .25-mfd capacitor.

Set the function switch of your tvom to ac and set the range switch to the 120-volt position. Clip the ground lead to the chassis and measure the ac voltage between terminal C1 and ground. If your reading is less than about 25 volts, set the range switch to the 30-volt position. Observe the reading and record it in the chart in Fig. 35-2. 12V

Now set the tvom to dc and measure the dc voltage across the load. Make this measurement and record your value in Fig. 35-2. Turn off the circuit.

Step 2: To show that 120-Hz ripple can be filtered more easily than 60-Hz ripple.

Convert your circuit to a full-wave rectifier by resoldering the free HV diode lead to terminal B2. Energize the circuit and measure the ac ripple voltage across the load resistor and the .25-mfd capacitor. Set the tvom to ac and touch the probe to terminal C1. Record the voltage in the space for Step 2 in Fig. 35-2.

Switch the tvom to dc, set the range switch to 120 volts, and measure the dc output voltage between terminal C1 and the chassis. Record the value and turn your circuit off.

Step 3: To measure the ac ripple voltage and the dc voltage across the load shunted by a higher capacitance.

The change to make in the circuit is shown in Fig. 35-3. Disconnect and remove the diode connected between terminals B2 and B4. Also, disconnect the lead of the .25-mfd capacitor from terminal C1. Connect a 20-mfd electrolytic capacitor from terminal C1 to terminal C4 or some other convenient ground terminal. The positive lead of the electrolytic capacitor must connect to terminal C1.

STEP	CIRCUIT	VOLTAGE MEASURED	
		AC	DC
1	47K Load Shunted by .25 MFD	12v	73v
2	F.W. Rectifier. 47K Load Shunted by .25 MFD	12v	73v
3	47K Load Shunted by 20 MFD	.4	86v
4	Choke and Two 20 MFD Capacitors	—	86v

Fig. 35-2. Enter your readings here for Experiment 35.

You are now ready to make your voltage measurements. Turn the power supply on and measure the ac ripple voltage across the load resistor. Record your reading in Fig. 35-2. Notice that the ac ripple voltage is extremely small compared to that obtained in Step 1, showing that the use of a larger capacitor at this point reduces the ripple.

When you are measuring ac voltages on the 1.2V or 3V range, you may notice that the meter pointer moves upscale, even when the probe is disconnected from the circuit. This is normal. It is due to stray voltage pickup. If the meter reads zero when the ground clip is shorted to the positive probe, the meter will read accurately when it is connected into a circuit.

Set your tvom to measure the dc voltage across the load, make this measurement, and record your results in Fig. 35-2. Turn off the power supply. Notice again the change between the readings in Step 1 and Step 3. Obviously, the large capacitor in the circuit caused the increase in the dc voltage.

Step 4: To show how the ripple voltage at the output of the rectifier can be reduced by a filter so that almost pure dc is applied to the load resistor.

The changes to be made are shown in Fig. 35-4. Unsolder and remove the length of hookup wire connecting terminals B4 and C1. Connect a second 20-mfd electrolytic capacitor from terminal B4 to terminal B7 with the positive lead to B4. Connect one lead of the choke coil mounted on your chassis to terminal B4. Connect the other choke lead to terminal C1. Solder all connec-

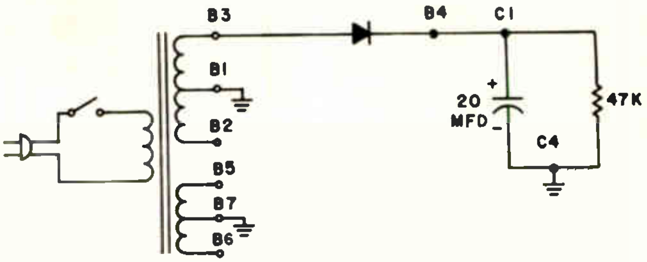


Fig. 35-3. The circuit for Step 3.

tions and recheck your wiring. You are now ready to continue making your measurements.

Set the tvom for ac measurements and measure the ac ripple voltage across the load resistor between the chassis and terminal C1. If you cannot measure any ripple voltage, simply make a dash in the space provided in Fig. 35-2. Now reset your tvom, and measure the dc voltage across the load resistor. Record your results in Fig. 35-2. Turn off the power supply.

Discussion: In this experiment, you have observed the fact that filtering the output of a rectifier increases the dc voltage and decreases the ac ripple voltage across the output.

In Steps 1 and 2, you saw that the small capacitor was better able to filter the full-wave rectifier output than the half-wave output. This is because the full-wave circuit produces two pulses of voltage during each cycle. Thus, the capacitor is recharged twice as often as it is in a half-wave circuit. The capacitor has less time to discharge between pulses and therefore, it maintains a higher average voltage.

The 20-mfd capacitor which you used in Step 3 produced a higher dc voltage with lower ripple than you obtained with the full-wave rectifier circuit and the small capacitor. Each time the rectifier conducted, the capacitor became fully charged. Because it has such a high capacity, the electrolytic capacitor stored more energy and discharged very little between pulses. Thus, the average dc voltage across it was high.

You should have measured nearly the

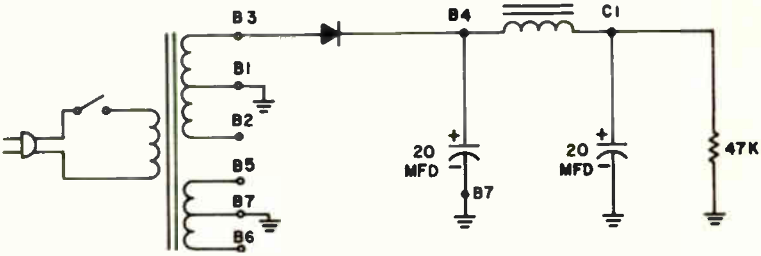


Fig. 35-4. The rectifier and π circuit for Step 4.

same dc voltage in Step 4 that you measured in Step 3, but with almost no ripple. The network which you used in Step 4 is a low pass pi filter, consisting of two capacitors and a choke. The capacitor connected between the cathode of the rectifier and ground is called the input filter capacitor and the one across the load is called the output filter capacitor.

Refer to the schematic diagram in Fig. 35-4. Notice that the choke, output filter and resistor form a load for the rectifier and input filter capacitor. The combined ac and dc voltage is applied to this load. The capacitor has low reactance to ac and high reactance to dc. On the other hand, the choke has high reactance to ac, and low reactance to dc. Thus, when applied to the choke and a capacitor, the ac and dc voltages divide differently.

Because the choke has high reactance to ac, most of the ac voltage is developed across it. The dc resistance of the choke is low compared to the dc resistance of the load resistor, resulting in little dc voltage drop across the choke. Most of the dc voltage, therefore, is developed across the output filter capacitor and the load resistor.

Pi filter networks using resistors instead of chokes are used in some low power equipment such as ac-dc receivers. The use of a resistor gives considerable savings in weight, space and cost. As long as the circuit current is not high, a circuit of this type can provide adequate filtering.

In order to provide the filtering, the value of the resistor must be high compared to the impedance of the output filter capacitor. The ripple voltage is developed across the resistor and the output filter capacitor in series. If the impedance of the capacitor is quite low, most of the ripple will appear across the resistor and little of it will appear across the load.

The dc current drawn by the load also flows through the filter resistor. Because the resistor value must be fairly high, there is a substantial voltage drop across it. This voltage drop is in series with the load, thereby making available less voltage for the load.

Instructions for Statement No. 35: For this statement, we are going to determine the ripple reduction factor of the filter circuit. To do this, we divide the amount of ripple voltage across the input filter capacitor by the amount of the ripple voltage across the output filter capacitor. For example, if you have 3 volts at the input and .1 volt at the output, you would divide 3 by .1, and obtain a ripple reduction factor of 30.

The circuit we will use is shown in Fig. 35-5. The .25-mfd capacitor is used as the input filter capacitor, so unsolder and remove the 20-mfd electrolytic capacitor connected to terminal B4 and connect the .25-mfd capacitor from terminal B4 to terminal B7 or C4.

Set the tvom for ac voltage measurements, and turn the range switch to the 120-volt position. Measure the ac ripple voltage at the rectifier cathode, terminal B4. If necessary, adjust the range switch
29V
to a lower range. Now measure the output ripple voltage across the load by touching the probe of the tvom to terminal C1. Reduce the setting of the range
.4
switch as necessary to get a usable reading. Now, divide the output ripple voltage into the input ripple voltage. The number you get as the answer is the ripple reduction factor. Turn off the power supply and answer the Statement here and on the Report Sheet.

290.
72.5/29.0

.4)29.80
28
12

72.5
.4
29.0

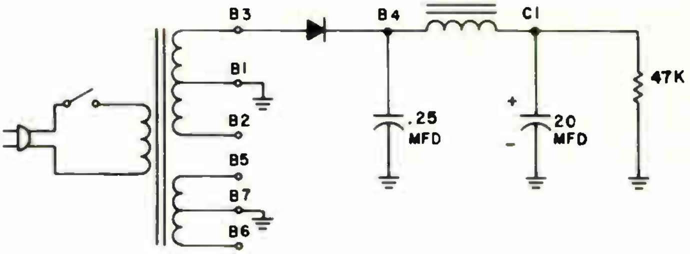


Fig. 35-5. The circuit used to answer Statement 35.

Statement No. 35: The ripple reduction factor for this experiment was:

(1) approximately 10.
[✓ *(2) between 20 and 80.*]
(3) more than 100.

EXPERIMENT 36

Purpose: To show the effect of a high power factor in the filter capacitors on the ac ripple voltage and the dc voltage at the output of a filter, and to show how servicemen check a capacitor for a high power factor.

Introductory Discussion: Electrolytic capacitors are used almost exclusively in radio and TV power supplies. An electrolytic capacitor, like all other capacitors, has two purposes. It acts as a high resistance for dc and a low resistance for ac.

As you have learned from your regular lessons, a perfect capacitor acts as an open, or offers an infinite resistance to the flow of dc. Also, in a perfect capacitor there is no loss during charge and discharge when ac is applied. In practice, these desirable results cannot be obtained. All capacitors have some leakage, and there is always some power loss.

A practical capacitor can be pictured as shown in Fig. 36-1. Fig. 36-1A shows the effect of leakage, and Fig. 36-1B shows the effect of power loss. In practical circuits, some leakage or some power loss can be tolerated. However, if the resistance of the leakage path becomes too small, circuit operation is affected, and we say that the capacitor is leaky or entirely shorted.

If the series resistance in Fig. 36-1B becomes too large, circuit operation is affected, and we say that the capacitor has developed a high power factor or has lost capacity. A high power factor is the result of an increase in the resistance between the capacitor plates themselves, or of drying out of the dielectric.

We will use the circuit shown in Fig. 36-2 to demonstrate the effects of high power factor in both the input and output filter capacitors.

Experimental Procedure: In addition to your tvom and the parts mounted on the chassis, you will need:

- 2 20-mfd, 150-volt electrolytic capacitors
- 1 3000-ohm resistor
- 2 22K-ohm resistors

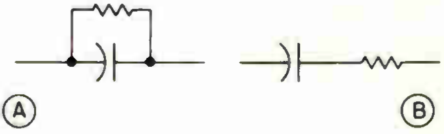


Fig. 36-1. (A) Leakage in a capacitor. (B) Power loss.

Proceed as follows: First remove the .25-mfd capacitor from terminal strip B and replace it with a 20-mfd, 150V electrolytic capacitor. Be sure to connect the positive lead to terminal B4. Disconnect the 47K-ohm lead resistor and replace it with two 22K-ohm resistors connected between terminals C1 and C4. Solder the connections.

Your circuit should now be wired as shown in Fig. 36-2. Check it over carefully, comparing it to Fig. 36-2. Examine both sides of the terminal strips to make certain that solder has not dripped down and shorted to the chassis.

Also, check for a short in the B supply with your ohmmeter, before applying power. To do this, set your tvom for ohmmeter measurements with the range switch in the R X 1K position. Put the ground lead on the chassis, and touch the positive probe to the rectifier terminal, B4. The capacitors will slowly charge up and should eventually give a reading of 11,000 ohms. This is the resistance of the load composed of the two 22K-ohm resistors in parallel. If the resistance is considerably less than this, there is a short or incorrect wiring, which you should find and correct before going on.

Step 1: To measure the normal dc and ac output voltages of the circuit shown in Fig. 36-2.

Set the function switch to dc, set the range switch to the 300-volt position and set the polarity switch to normal. Clip the tvom ground lead to the chassis, turn on the power supply and touch the positive probe to terminal C1. Record the reading as the dc output voltage for Sfep 1 in Fig. 36-3. 570

Now set up your tvom for ac measurements, and measure the ac voltage between terminal C1 and the chassis. If no perceptible voltage is present even on the 1.2-volt range, make a dash in the space provided, or record any reading you obtain. Turn off the supply.

Step 2: To determine the effect of a high power factor in the input filter capacitor on the dc output voltage and the ac ripple voltage.

To simulate a high power factor in the input filter capacitor, disconnect the positive capacitor lead from terminal B4. Solder one end of the 3000-ohm resistor to terminal B4, and then solder the capacitor lead to the other lead of the 3000-ohm resistor, as shown in Fig. 36-4. Arrange these two leads so that they will not touch the chassis. You can now imagine that the resistor is actually inside the capacitor, in series with the positive lead and the capacitor plates. You can consider the end of the 3000-ohm resistor

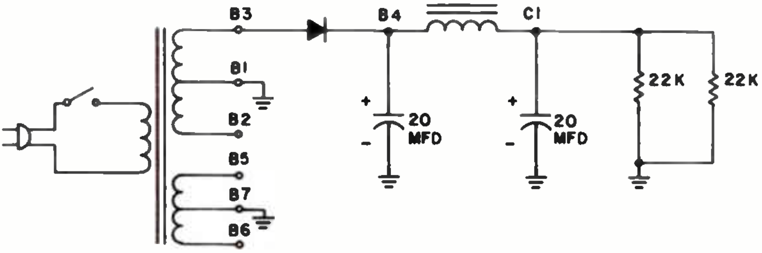


Fig. 36-2. The circuit for Step 1.

STEP	CIRCUIT CONDITIONS	OUTPUT VOLTAGE	
		DC	AC
1	Normal	80V	0
2	High Power Factor in Input Capacitor	50	.3V
3	Defective Input Capacitor Shunted by Good Capacitor	80V	0
4	High Power Factor in Output Capacitor	78V	.5V

Fig. 36-3. Enter your readings here for Experiment 36.

connected to terminal B4 as the capacitor lead. Now we will measure the dc and ac output voltages with a defective input capacitor to see what has happened.

Set up your tvom to measure dc voltages as you did before, with the switch in the 300-volt position. Measure the dc voltage between terminal C1 and the chassis. Reduce the range switch setting if necessary to a lower range, and record the reading for the dc output voltage in Step 2.

Now measure the ac output voltage between the chassis and terminal C1. If there is no perceptible reading, indicate this by a dash; but if you do get a reading, show the value in the space for ac output voltage in Step 2 in Fig, 36-3. Turn off the supply.

You should find that the dc output voltage has dropped considerably, and you should have been able to measure an ac output voltage, showing that the ripple voltage at the input of the filter has increased considerably.

Now let us see how a serviceman would test a defective capacitor by using a good one of the same size.

Step 3: To determine the effect of shunting a suspected capacitor with one of approximately the same size known to be in good condition.

Connect your dc voltmeter between the chassis and terminal C1, using the slip-on alligator clip over the positive probe. Turn the power supply on, and note the voltage reading. Now pick up the third 20-mfd, 150-volt electrolytic capacitor, holding it by the case. Note carefully the positive and negative markings. Hold the capacitor with the negative lead touching the chassis and move the capacitor around until its positive lead touches terminal B4. You may notice a snap or spark when the connection is made. Hold the capacitor firmly in place, keeping your fingers off the hot lead. Notice the effect on the output voltage. It should increase almost to its original value. Record this value in Fig. 36-3 as the dc output voltage for Step 3.

Then, still holding the capacitor carefully by its case, lift it up and touch both leads to the chassis. The capacitor will discharge with a sharp snap and spark. Always discharge a capacitor, because if you don't, you might get an unpleasant

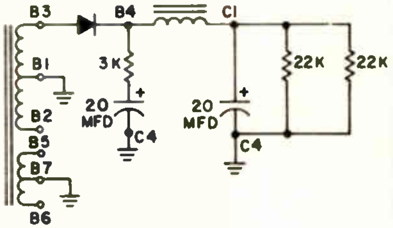


Fig. 36-4. The circuit for Step 2.

shock later. There is no danger as long as you hold the capacitor by its insulating case.

Leave your voltmeter connected to the output of the power supply, turn off the power supply, and set the voltmeter switches for ac measurements. Turn the power supply back on, and note that you still get the same reading as in Step 2 for the ac output voltage. Now, again hold the negative lead of the 20-mfd capacitor against the chassis, and allow the positive lead to touch terminal B4. Notice that when the capacitor makes contact across the defective capacitor, the ac output voltage drops to the same value as Step 1 for ac output voltage. Record this in Fig. 36-3.

Thus, you have seen what happens when an input capacitor develops a high power factor, and you have seen that you can check the capacitor by shunting it with a good one of about the same size. In a test like this, you must be sure to use the proper polarity. If you were to reverse the polarity on the test capacitor, you would probably ruin the capacitor. Even if it did not damage the part, the test would be worthless with the capacitor connected in this manner.

You have now finished the tests with the input filter capacitor; so remove the 3000-ohm resistor from the circuit, and unsolder the positive lead of the input capacitor from the resistor lead. Resolder the positive lead to terminal B4. The circuit is now the same as in Fig. 36-2.

Step 4: To show the effect of a high power factor in the output filter capacitor.

Disconnect the positive lead of the electrolytic capacitor from terminal C1. Solder one lead of the 3000-ohm resistor to lug C1. Then, solder the positive capacitor lead to the free resistor lead. Place the two leads so they cannot touch the chassis.

Connect the ground clip of the tvom to the chassis of the power supply, and connect the positive probe to terminal C1. Set your tvom to measure the dc voltage across the 11K-ohm load resistor, and turn the range switch to the 300-volt position. Turn on the power supply, and record the reading in the space for dc output voltage for Step 4 in Fig. 36-3.

The voltage should be the same as that in Step 1 in Fig. 36-3. This shows that a high power factor in the output filter capacitor has no effect on the dc output voltage. Now turn off the power supply.

Set the function switch to ac, and turn on the power supply. Reduce the range switch setting a step at a time until you get an easily read ac output voltage. Record this voltage in the space provided for ac output voltage in Step 4 in Fig. 36-3. Note that this voltage is considerably higher than in Step 2, showing that the filter action has definitely been affected.

Now, with the equipment still turned on and your meter indicating the ac output voltage, take your 20-mfd test capacitor, touch the negative terminal to the chassis, and the positive terminal to terminal C1 or to any point in electrical contact with C1. Good contact is necessary. The ac output voltage should drop to zero. Discharge your capacitor by touching both of its leads to the chassis of the power supply, and turn off the supply.

Discussion: From the tests you have made, you have learned that a defect in the input capacitor does not affect the circuit in the same way as one in the output capacitor. You have learned the following facts:

(1) A high power factor in an input filter capacitor decreases the dc voltage and increases the ac ripple voltage at the output.

(2) A high power factor in the output filter capacitor has no effect on the dc operating voltages but increases the ac ripple voltage across the load considerably.

In both cases, the capacitor can be easily tested by shunting it with a good one of about the same size. If the symptoms clear up, the one being tested is definitely bad, and should be replaced. The test capacitor does not need to have exactly the same capacity, but should have a working voltage at least equal to that of the one under test. Also remember that you must observe the proper polarity when making these tests. Immediately after making the test, discharge the test capacitor by touching its two leads to the chassis.

Instructions for Statement No. 36: You have seen the effect of a high power factor in both the input and output filter capacitors. The lead connecting to the foil inside the case may break, thus opening the capacitor. We are going to simulate this by disconnecting one of the capacitor leads and checking the ripple voltage. You are to find out the results of an actual open in the output filter capacitor compared to the results of a high power factor that you simulated by using the 3000-ohm series resistor.

Disconnect the positive capacitor lead from the 3000-ohm resistor, remove the 3000-ohm resistor from the circuit, and arrange the free capacitor lead so that it cannot short to the chassis. Clip your tvom to the chassis and to terminal C1. Set your tvom for ac measurements, turn on the power supply, and note the reading. You will then be able to answer the Statement. 1V AC

Statement No. 36: When I simulated an open in the output filter capacitor, I found that the ac voltage across the load resistor was:

(1) less than
[✓ *(2) more than*]
(3) the same as

the ac output voltage in Step 4.

EXPERIMENT 37

Purpose: To show how two rectifiers can be connected to a voltage source to give twice the voltage that can be obtained from a single rectifier; and to show how they can be used for either half-wave or full-wave rectification.

Introductory Discussion: Tubes used in ac-dc radio receivers today are designed to operate on power supply voltages of 90 to 100 volts dc. A half-wave rectifier that is capable of supplying this voltage is shown in Fig. 37-1. It is the type of rectifier circuit that is usually found in ac-dc receivers. The tubes used in early ac-dc receivers required 180 volts dc or more. Therefore, vacuum tube rectifier circuits that could double the line voltage were used in these receivers. They are not often found in today's inexpensive ac-dc sets.

Voltage doublers, however, are widely used in TV sets, where eliminating the power transformer gives a much greater saving than in a radio receiver. You are likely to have to work on one at some time in your servicing career. For this

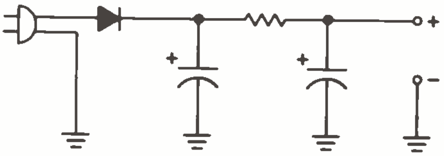


Fig. 37-1. A rectifier circuit capable of supplying about 90V dc.

reason, the study of how voltage-doubler power supplies operate is important to you.

Voltage-doubler power supplies are divided into two types: full-wave and half-wave. The full-wave doubler is generally used in supplies where the current demands are heavy and where an isolation transformer is used. Its output voltage has a ripple frequency of 120 Hz. Therefore, it can be more easily filtered than the output voltage of a half-wave voltage doubler, which has an output ripple of 60 Hz.

The half-wave voltage doubler is often used in TV receivers which have no power transformers. The ac line is connected directly to the negative side of the doubler circuit. You may also see half-wave doublers in TV high voltage supplies because in the high voltage supply the current demands are very low. Hence, filtering is not a problem.

Instead of using the power line directly as a source of voltage in this experiment, we will use half of the high voltage winding of the power transformer. This gives protection from the power line and permits us to experiment with somewhat lower voltages. Regardless of the source voltage used, the basic principles are the same.

Experimental Procedure: In addition to your tvom and the power supply parts, you will need:

1 20-mfd, 150-volt electrolytic capacitor
1 .25-mfd capacitor
1 12BA6 tube

Examine your soldering iron tip to be sure it is clean and well tinned.

You must first partially dismantle your power supply. Remove the two 22K-ohm resistors from terminals C1 and C4. Unsolder the two choke leads, and unsolder the red/yellow transformer lead from terminal B1. Also disconnect the two 20-mfd electrolytic capacitors. Remove any excess solder on the terminal strips, and make certain that no solder has bridged from the lugs to the chassis.

Fig. 37-2A shows how a rectifier can be connected to an ac voltage source to produce a rectified voltage that is positive with respect to the red/yellow side of the voltage source. Fig. 37-2B shows a rectifier connected to produce a rectified voltage that is negative with respect to the red/yellow side of the voltage source. We will combine these two circuits to

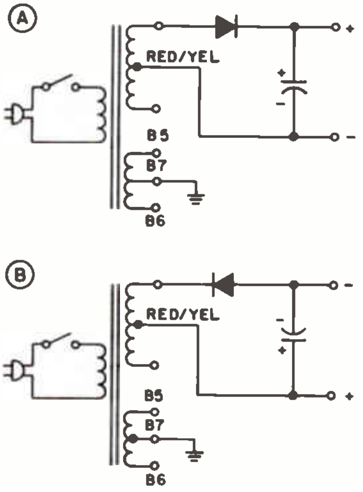


Fig. 37-2. Rectifier connected to (A) a positive supply and (B) a negative voltage with respect to the transformer center tap.

make a full-wave voltage doubler. The circuit is shown in Fig. 37-3.

Wire the circuit shown in the schematic diagram in Fig. 37-3. First, connect the red/yellow transformer lead to terminal B4. Connect a rectifier diode from terminal B3 to terminal A6; the cathode connects to A6. Connect another rectifier diode from terminal A4 to terminal B3. Connect the cathode to B3. Connect a 20-mfd, 150V electrolytic capacitor from terminal A4 to terminal B4, with the positive lead to B4. Connect another 20-mfd electrolytic capacitor from terminal B4 to terminal A6, with the positive lead to A6. Check your work against the schematic and solder all connections.

Check the connections carefully, because when more than two leads are soldered to a single terminal, it is very easy for one of the leads, usually the one on the bottom, to come loose. The circuit is now wired as shown in Fig. 37-3, and you can proceed with the experiment.

Step 1: To show that the circuit in Fig. 37-3 gives twice the voltage that a single rectifier would.

Measure the ac source voltage between terminals B4 and B3. Record your measurement in Fig. 37-4. Turn off the supply after each measurement.

65v

Now measure the dc output voltage of rectifier D_1 by measuring across capacitor

70v

C_1. Connect the ground clip of the tvom to terminal B4, and the probe to terminal A6. Note the polarity marked on the electrolytic capacitor in Fig. 37-3 so you will know how to set the polarity switch on the tvom. Record your reading in Fig. 37-4.

Measure the dc voltage developed by rectifier D_2 by measuring the voltage

80v

across capacitor C_2. Leave the ground clip of the tvom on terminal B4, note the polarity of the voltage to be measured as shown on the electrolytic capacitor in Fig. 37-3, and set your polarity switch accordingly. Touch the probe to terminal A4, and record the voltage you measure in Fig. 37-4.

As you can see from Fig. 37-3, capacitors C_1 and C_2 are in series, so that the voltages across them add. Measure this voltage by clipping the ground lead of the tvom to terminal A4, note the polarity so you can set the polarity switch properly, and put the range switch in the 300-volt position. Touch the probe to terminal A6, and record your voltage in Fig. 37-4 as the dc output without load. You should get approximately twice the voltage that you got across either C_1 or C_2.

180v

Notice that the dc voltage is much higher than the peak of the rectified ac source

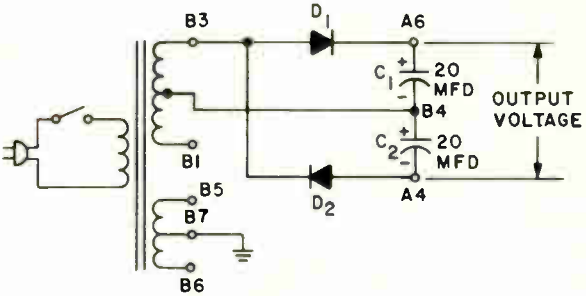


Fig. 37-3. The full-wave voltage doubler circuit.

VOLTAGE MEASURED	READING
AC Source	65V
DC Output of Diode D_1	90V
DC Output of Diode D_2	86V
DC Output Without Load	180V
DC Output Under Load	170V

Fig. 37-4. Enter your readings for Step 1 here.

voltage. Turn off the power supply. As a final measurement in this step, let us see how much the output voltage drops when a load is applied. Connect the two 22K-ohm resistors in series, and connect the outside leads of the 44K-ohm resistance between terminal A4 and terminal A6. Solder the connections. Now measure the dc voltage between terminals A4 and A6, and record the value in the space provided in Fig. 37-4. Note that the voltage dropped when the load was applied just as you have observed in the various rectifier circuits with which you previously experimented.

Before starting to disassemble this circuit, you should discharge the filter capacitors. To discharge the capacitors, strip a quarter of an inch or so of insulation from both ends of a 6-inch piece of hookup wire. Unplug the chassis from the power line, and holding the wire by the insulation, short terminal A6 to terminal B4. You may see a spark as the capacitor discharges. Do this several times. Now discharge capacitor C_2 by touching the ends of the hookup wire to terminals B4 and A4. When the capacitors have been discharged, it will be safe to touch the circuits without danger of shock.

Step 2: To show that in a half-wave voltage doubler, the rectified voltage stored in one capacitor is added to the line voltage so the sum of the two voltages acts as the source voltage for the second rectifier.

The circuit that you will use is shown in Fig. 37-5. First, remove the 44K-ohm load resistor (the two 22K-ohm resistors in series) from terminals A4 and A6. Unsolder and disconnect capacitor C_2 from terminals A4 and B4. Move the red/yellow transformer lead from B4 to A4. Move the negative lead of capacitor C_1 from B4 to A4.

Move both diode leads from terminal B3 to terminal B4. Connect capacitor C_2 between terminals B3 and B4, with the positive lead to B4. Solder all connections and check your work against the schematic in Fig. 37-5.

To measure the ac source voltage, set up your tvom for ac voltage measurements, and connect the ground clip to terminal B3. Turn on the power supply, and touch the probe to terminal A4. Record the ac voltage measured in Fig. 37-6.

Now, set your tvom for positive dc voltage measurements. With the ground

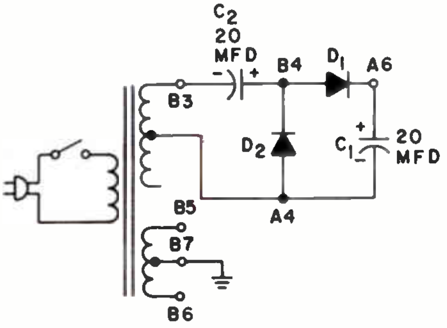


Fig. 37-5. The half-wave voltage doubler circuit.

lead connected to terminal B3, touch the probe to terminal B4. The voltage you measure is that developed across capacitor C_2, the 20-mfd, 150-volt capacitor connected between these terminals. Record the value in Fig. 37-6.

To measure the voltage at the output of rectifier D_1, turn off the power supply, connect the ground lead of the tvom to terminal A4, set the range switch to the 300-volt range, turn on the power supply, and touch the probe to terminal A6. Record the voltage you measure in Fig. 37-6. Note that it is approximately the same as the dc output voltage in Step 1 of Fig. 37-3. Turn your equipment off.

Discussion: In Fig. 37-3 the rectifiers function on alternate cycles of the power line, so the ripple voltage developed in the circuit between the output terminals (A4 and A6) is 120 Hz.

When the red transformer lead is positive with respect to the red/yellow lead in Fig. 37-3, we have current flow through rectifier D_1, which charges capacitor C_1 with the polarity shown. (Remember that the lead marked + on the rectifier is actually the cathode.) When the ac across the power transformer has this particular polarity, rectifier D_2 will not conduct. On the next half-cycle, the red/yellow lead is positive with respect to the red lead. Then rectifier D_1 will not conduct. However, rectifier D_2 does conduct, and in so doing, charges capacitor C_2 with the polarity shown. The two capacitors, of course, retain their charges, and since they are in series with the correct polarity, the voltage between terminals A4 and A6 is twice that of either capacitor.

In the half-wave voltage doubler in Fig. 37-5, there is a 60 Hz ripple between the output terminals A6 and A4. When the red lead in Fig. 37-5 is negative with respect to the red/yellow lead, rectifier D_2 will conduct, charging up capacitor C_2 to the polarity shown. This time rectifier D_1 will not conduct. On the next half-cycle, the red lead becomes positive with respect to the red/yellow lead and the voltage across C_2 is added to the transformer voltage. The polarity is incorrect for conduction through D_2, but D_1 will conduct, and its output will charge C_1 to the peak of this voltage. As you have seen, it is roughly equal to the output voltage of the full-wave doubler.

Note in Fig. 37-5 that one side of the ac source (the red/yellow lead) is connected to the negative side of the output at terminal A4. Therefore, the half-wave doubler can be used without an isolation transformer in an ac line operated receiver, since one line is common to the input and the output of the power supply.

Voltage doubler circuits, such as those in Figs. 37-3 and 37-5, are able to double the source voltage only when operated on ac voltage. They will not act as doublers if the line voltage is dc. This is of little importance because there are few areas today where dc power line voltage is available.

Voltage doublers have the same difficulties as ordinary power supplies. The filter capacitors become leaky or develop

VOLTAGE MEASURED	READING
AC Source	64V
Voltage Across C_2	90V
Voltage Output	176V

Fig. 37-6. Enter your readings for Step 2 here.

a high power factor and the rectifiers may fail. Where a high power factor is suspected, the capacitors can be checked by shunting them with others of about the same size known to be in good condition. Where you suspect leakage, the capacitors are checked with an ohmmeter.

Instructions for Statement No. 37: In the high voltage supplies of TV receivers, voltage triplers are often used. You will build such a system to get the information to answer the Statement.

Insert the 12BA6 tube in the socket on the circuit board. You should still have leads connecting terminals B5 and B6 to lugs 1 and 2 of the circuit board for the 12BA6 heater voltage. Disconnect the power supply from the ac line. Run a lead from lug 4 on the circuit board to terminal B3 and solder both connections. Make certain that the connections already on terminal B3 do not come loose.

Connect a .25-mfd capacitor from lug 5 on the circuit board to terminal A4, again taking care that the leads already connected to terminal A4 do not come loose, and solder does not drip down and short to the chassis. You should have a wire connecting lugs 3 and 5 on the circuit board. The circuit should now be wired like that shown in Fig. 37-7.

Connect the ground clip of your tvom to the .25-mfd capacitor lead that goes to lug 5. Clip the positive probe of the tvom to terminal A6. Plug the power supply in, and turn it on. Note that the voltage goes up to approximately 170 volts, and then drops down as the .25-mfd capacitor slowly discharges. As the tube heats up, the voltage will start to rise rather rapidly, and will soon come to a stop. Record the voltage you measure on the margin of this page. You are now ready to answer the statement.

200v

Statement No. 37: The voltage I measured between the plate of the 12BA6 tube and terminal A6 was approximately:

(1) twice
[✓ *(2) three times*]
(3) the same as

that across capacitor C_2 in Step 2.

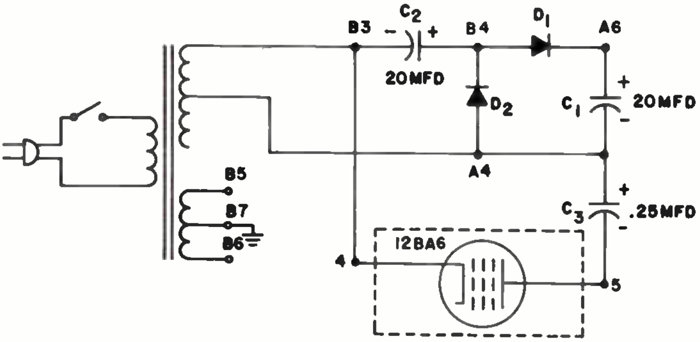


Fig. 37-7. The circuit for Statement 37.

Tube And Transistor Fundamentals

In the following experiments, you will demonstrate triode vacuum tube and transistor fundamentals. You will then use the tube and transistor in voltage regulator circuits. We will review briefly the operation of tubes and transistors before going further.

You know that a tube passes current from cathode to plate. The current is in the form of electrons which are emitted by the heated cathode. When the plate is at a positive potential, the electrons are attracted to it.

The control grid, which is an element placed near the cathode in triodes, tetrodes, pentodes, etc., controls the electron flow, and hence the amount of current reaching the plate. The cathode-to-grid voltage or bias is normally slightly negative. By varying the bias, the plate current can be increased or decreased.

As you learned from your regular lessons, a transistor is similar to a triode tube. It has three elements - a collector, base and emitter, and can be used for many of the functions served by vacuum tubes.

Bipolar transistors, which are the most widely used type of transistor, are made in either of two classifications: PNP or NPN. You received a PNP type in this kit. In a PNP transistor, current passes from collector to emitter. This conduction takes place when the base is more negative than the emitter and the collector is more negative than the base.

The amount of collector-to-emitter current is controlled by the emitter-to-base current. The collector current increases as the base-to-emitter current increases.

EXPERIMENT 38

Purpose: To show that when the plate of a triode tube is positive with respect to the cathode, the tube can complete a path for direct current and to show that grid-to-cathode voltage can control the conduction of a triode.

Introductory Discussion: In previous experiments, you have connected two or more resistors in series across the battery and have noted how the battery voltage divides between the resistors. We will repeat this experiment using the high voltage supply instead of a battery. We will first simulate the cathode-plate circuit of a tube with a resistance. Then we will substitute the cathode-to-plate path of the tube for one of the resistors. You will find that the voltage will still divide between the remaining resistor and the cathode-plate path within the tube. You will use various values of resistors in series with the tube and see that the voltage division will change when one of the resistors in the circuit changes.

Following this, you will see that the series resistor can be placed between the negative side of the power supply and the cathode of the tube or between the plate and the positive side of the supply. You will find that the tube operation is similar in either case. You will see how we can vary the cathode-plate resistance of a tube. You will use a low voltage battery to supply bias voltage and measure the resulting plate current.

In this experiment you will use your 12BA6 tube connected as a triode. Previously, you used it as a diode, with the control grid connected to the plate. Now you will have to disconnect the control grid from the plate circuit, as the control grid will be supplied separately. Always be sure to turn off the supply and discharge the capacitors before you make circuit changes to avoid being shocked.

Experimental Procedure: For this experiment, you will need the following parts in addition to the experimental chassis and your tvom:

1 **100K-ohm resistor**
2 **22K-ohm resistors**
2 **1.5-volt flashlight cells**

Fig. 38-1 shows the circuit you will use in the first step of this experiment. The circuit consists of a half-wave rectifier power supply and a voltage divider. The 100K-ohm resistor we will call the load resistor, R_L, and the 44K-ohm resistance will represent the cathode-to-plate resistance of the tube. Before wiring the circuit, unsolder and remove from the chassis the two rectifiers and the three capacitors used for Statement 37. Also unsolder the red/yellow power transformer lead from terminal A4 and solder it to terminal B1. Remove the lead connected between terminal B3 and lug 4 of the circuit board.

Now connect a rectifier diode between terminals B3 and B4, with the cathode lead connected to B4. Connect a 20-mfd, 150V electrolytic capacitor between terminals B4 and B1, with the positive lead to B4.

Connect a 100K-ohm resistor between terminal B4 and lug 5 of the circuit board. If necessary, solder a short length of wire to the resistor lead. Connect the series-connected 22K-ohm resistors from terminal C4 to lug 5.

If you have not already done so, remove the 12BA6 tube from the tube socket. Also, remove the wire connecting lugs 3 and 5 on the circuit board. Note that you have a series circuit connected across the high voltage power supply and you are using lug 5 of the circuit board merely as a tie point.

Step 1: To measure the voltage drop across the 44K-ohm resistance.

Connect the ground lead of your tvom to the chassis and set the meter for measuring positive dc voltage on the 120-volt range. Plug the experimental chassis power cord into an ac receptacle and turn the equipment on. Touch the probe of your tvom to lug 5 and measure the voltage. Record the measurement under "Plate-Cathode Voltage" in the space for Step 1 in the chart in Fig. 38-2. 28v This is the voltage drop across the 44K-ohm resistance.

The voltage drop across the 100K-ohm load resistor can now be found by measuring the B supply voltage at terminal B4 and subtracting the voltage drop across the 44K-ohm resistance. For example, if the voltage across the 44K-ohm resistance

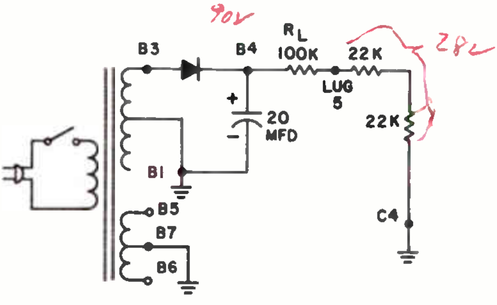


Fig. 38-1. The circuit used in Step 1.

90V
28
62
90

90.0
1.4
88.6

90.0
4.6
85.4

90.0
84.0
6.0

90
37
53

STEP	PLATE CATHODE VOLTAGE	VOLTAGE ACROSS R_L
1	28V	62V
2	1.4V	88.6V
3	4.6V	85.4V
4	6V	84.0V
5	37V	53V

Fig. 38-2. The chart you will use for Experiment 38.

is 24 volts, and your B supply voltage is 80 volts, the voltage across the 100K-ohm resistance is 56 volts. For convenience we call this resistor R_L. Enter the voltage you calculated for the drop across R_L in the proper space in Fig. 38-2.

Step 2: To measure the plate voltage of a tube with a 100K-ohm load resistor.

Change the circuit so it will be wired according to the schematic in Fig. 38-3. Unsolder and remove the 44K-ohm resistance. Connect a length of hookup wire from lug 4 on the circuit board to terminal C4. Connect a short length of hookup wire from lug 4 to lug 3 of the circuit board. Finally, insert the 12BA6 in the socket.

Connect your tvom to measure the dc voltage at the plate, pin 5, of the tube (lug 5). Turn the circuit on and notice that the voltage rises immediately to the B supply voltage. As the tube warms up, the voltage will decrease. Record the plate voltage in Fig. 38-2. Subtract it from the B supply voltage value and record the difference as the voltage across R_L. Turn off the circuit and discharge the filter capacitor of the power supply.

Step 3: To show that decreasing the plate load resistance increases the plate voltage.

Remove the 100K-ohm load resistor connected between terminal B4 and circuit board lug 5. The two 22K-ohm resistors should still be connected in series. Connect them in place of the 100K-ohm resistor.

Turn the circuit on and allow time for the tube to warm up. Then measure the voltage at the plate of the tube, lug 5. Record this as the plate voltage for Step 3 and compute the voltage drop across the load resistance R_L. Record this voltage also in Fig. 38-2.

Step 4: To show that the load resistor can be in either the plate or cathode circuit.

You will use the circuit in Fig. 38-4. After turning the circuit off and discharging the filter capacitor, unsolder and remove the 44K-ohm load resistance. Connect a piece of hookup wire in its place between lug 5 and terminal B4. Remove the length of hookup wire connected in the cathode circuit between terminal C4 and lug 4 of the circuit

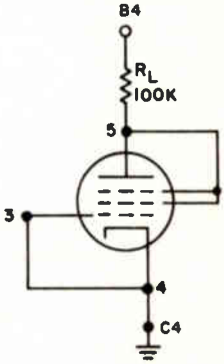


Fig. 38-3. The circuit for Step 2.

board. In its place, connect the 44K-ohm resistance.

Connect your voltmeter across the 44K-ohm resistance and turn the circuit on. Note that the voltage is zero at first and rises gradually as the tube warms up.

Because the meter is connected directly across the load resistance, you are measuring the voltage across R_L. Record this voltage in the space for R_L for Step 4 of Fig. 38-2. Subtract this voltage from the B supply voltage and enter the difference in Fig. 38-2 as the plate voltage.

Step 5: To show that the grid voltage will vary the resistance of the cathode-plate path.

With the circuit turned off, unsolder and remove the 44K-ohm resistance and connect a length of hookup wire in its place, between terminal C4 and lug 4. Remove the length of hookup wire between lug 5 and terminal B4. Connect the 44K-ohm resistance in its place.

The two 1.5-volt D cells should be still connected in series to form a 3-volt battery. If they are not, reconnect them. Connect the battery between the cathode and grid of the tube as shown in Fig. 38-5. Solder the positive battery lead to a convenient ground terminal and the negative battery lead to lug 3. Check your work to see that the circuit is wired according to Fig. 38-5.

Connect your tvom to measure the dc voltage between the chassis and the plate of the tube at circuit board lug 5. Energize the circuit. Allow time for the tube to warm up and observe the voltage reading. Record the plate voltage for this step in Fig. 38-2. Compute the voltage across R_L and record it in the chart. Turn the equipment off.

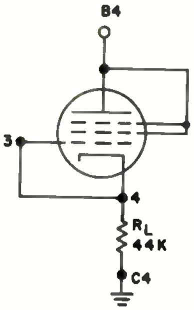


Fig. 38-4. The tube with the load resistance in the cathode circuit.

Discussion: In this experiment you have demonstrated some of the very important facts about vacuum tube circuits. These are:

(1) The cathode-plate path inside a tube will conduct current and this path has a definite resistance.
(2) If a resistor is placed in series with either the plate or cathode, the source voltage will divide between the tube and resistor.
(3) Changing the value of the resistor will change the voltage division between the tube and the load resistor.
(4) If a voltage is applied that makes the grid of the tube negative with respect to the cathode, the tube acts as a higher resistance and it conducts less current.

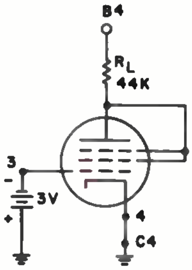


Fig. 38-5. The circuit for Step 5.

(5) When the load, R_L, is in the plate circuit, the plate voltage is equal to the supply voltage less the drop across R_L.

Instructions for Statement No. 38: For this statement, you will determine whether or not or how much current flows in the grid circuit used in the last step.

Unsolder the negative battery lead from circuit board lug 3 and connect a 100,000-ohm resistor in series between the battery lead and lug 3. Turn the circuit on and allow the tube to warm up. Measure the voltage across the 100K-ohm resistor. Using the Ohm's Law formula for current (I = E/R) compute the grid current. Answer the Report Statement here and on the Report Sheet. Turn the circuit off.

Unsolder and disconnect the 3-volt battery from the chassis. Unsolder and disconnect the 44K-ohm resistor. Also remove the length of hookup wire connected between lug 4 and terminal C4.

Statement No. 38: The grid current in the vacuum tube circuit with negative grid voltage was:

(1) between 5 and 15 ma.

(2) more than 20 ma.

[✓ *(3) less than 1 ma.*]

EXPERIMENT 39

Purpose: To show that a transistor consists of two semiconductor junctions and to show that the base-emitter current can affect emitter-collector path resistance.

Introductory Discussion: You will use your power transistor in this experiment. This is a PNP-type germanium power transistor. The designation PNP refers to the characteristics of the materials which make up the emitter, base and collector elements of the transistor. The base is doped with a donor material which gives it an excess of electrons or negative characteristics. The emitter and collector are doped with an acceptor material. This material takes electrons from the germanium and leaves the emitter and collector with positive characteristics.

When a voltage is applied to a PN junction so that the negative voltage is applied to the N-type material and a positive voltage is applied to the P-type material, we say that the junction is forward biased. When the opposite polarity is applied, of course, the junction is reverse biased. For proper operation of a transistor, the base-emitter junction must be forward biased and the base-collector junction must be reverse biased.

Experimental Procedure: For this experiment, you will need the experimental chassis (with the transistor mounted), your tvom and the following:

1 100-ohm resistor
1 1,000-ohm resistor
1 47K-ohm resistor
1 10K-ohm resistor
2 1.5-volt flashlight cells

Be sure the chassis is turned off or unplugged from the power line for the first two steps of this experiment.

Step 1: To measure the dc resistance between the elements of the transistor.

You will use the ohmmeter section of your tvom to measure between the terminals of the transistor, which are identi-

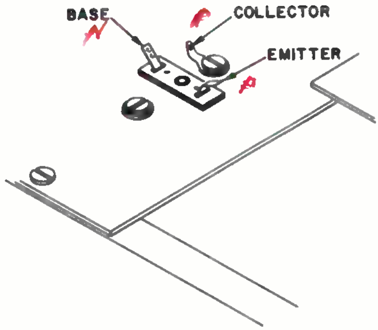


Fig. 39-1. How to identify the power transistor terminals.

fied in the sketch in Fig. 39-1. You will record your readings in the chart in Fig. 39-2.

Begin by measuring the forward resistance of the base-emitter junction. Set the tvom function switch to ohms and set the polarity switch to normal. Now the probe of the tvom is positive with respect to the clip. This is a PNP transistor so connect the tvom clip (negative) to the base and touch the probe (positive) to the emitter. Use the R X 100 range. Read the meter and record the resistance in the space for the B-E (base-emitter) forward resistance.

Switch your tvom to reverse and measure the resistance of the base-emitter junction in the reverse direction. Use the R X 1K or R X 10K range and record the resistance reading in the chart.

Now move the probe to the collector terminal, set the polarity switch to normal and measure the forward base-collector resistance. Use an appropriate ohmmeter range. Record the resistance in Fig. 39-2.

Switch the polarity to reverse, choose a convenient ohmmeter range and measure the base-collector resistance in the reverse direction. Place this value in the chart.

Now move the clip of the tvom to the emitter terminal, set the polarity to normal and measure the emitter-collector resistance. Place this value in the first column in the chart. Switch the tvom to reverse and take the final resistance reading. Touch the probe to the collector and measure the emitter-collector resistance in the opposite direction. Record this value in the chart.

Step 2: To measure the currents crossing the transistor junctions.

For this step, you will make indirect current measurements. You will measure the voltage drop across either a 100-ohm resistor or a 10,000-ohm resistor and compute the current by using the Ohm's Law formula, I = E/R. When you use the 100-ohm resistor, the current in milliamperes (ma) will be 10 times the voltage reading in volts. For example, a reading 2.4 volts across 100 ohms is 24 ma. When you use the 10,000-ohm resistor, the current in ma is 1/10 the voltage reading in volts. Thus, a reading 2.4 volts across 10,000 ohms represents a current of .24 ma or 240 microamperes (μa).

BASE-EMITTER		BASE-COLLECTOR		EMITTER-COLLECTOR	
FORWARD	REVERSE	FORWARD	REVERSE	NORMAL	REVERSE
100Ω	50K	14Ω	40K	6K	250

Fig. 39-2. Record your results for Step 1 here.

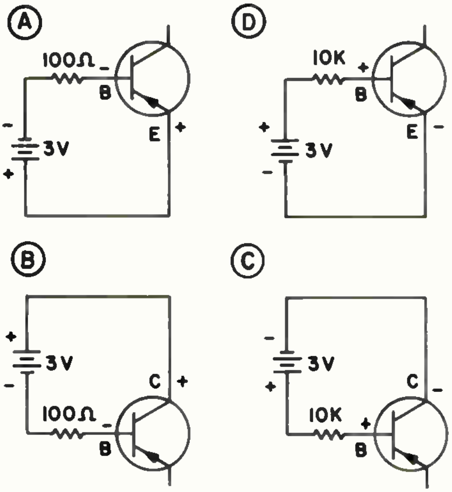


Fig. 39-3. Connections for measuring the forward and reverse currents of the two transistor junctions.

Wire the circuit shown in Fig. 39-3A. You should still have the two 1.5V flashlight cells connected in series, forming a 3-volt battery. Solder one lead of a 100-ohm resistor and a 10,000-ohm resistor to the transistor base terminal. Solder the positive lead of the 3-volt battery to the emitter terminal and solder the negative battery lead to the free lead of the 100-ohm resistor. Measure the dc voltage across the 100-ohm resistor, compute the current and record the value in the space for the base-emitter forward current in the chart in Fig. 39-4.

Change your wiring to that shown in Fig. 39-3B. Note that the negative battery lead still connects to the 100-ohm resistor and the positive battery lead is now connected to the collector terminal. Measure the voltage drop across the 100-ohm resistor and compute the forward base-collector current. Record the value in the chart in Fig. 39-4.

Modify your circuit as shown in Fig. 39-3C. Replace the 100-ohm resistor with the 10K-ohm resistor and reverse the battery polarity. Measure the voltage drop across the 10K-ohm resistor and compute the current. Record it in the space for base-collector reverse current in the chart in Fig. 39-4.

Change your circuit to that shown in Fig. 39-3D by moving the negative battery lead to the emitter terminal. Measure the voltage across the 10K-ohm resistor, compute the current and record it in the space for the base-emitter reverse current in Fig. 39-4.

Discussion of Steps 1 and 2: Thus far, you have proved two important facts about transistors:

(1) They consist of two PN junctions which act very much like semiconductor diodes, and

(2) the emitter-collector resistance is relatively high in both directions.

In Step 1, the low voltage across the ohmmeter leads biased the junction being measured. When applied in the forward direction, this caused the junction to pass current readily and, in turn, gave a low resistance reading. On the other hand, when you reversed the tvom polarity, you reversed the polarity of the voltage applied to the transistor junction. The slight reverse bias was sufficient to reduce the conduction of the junction and produce a very high resistance reading.

The diode action of the junctions was shown more clearly in Step 2 in which you used an external battery and series

	FORWARD	REVERSE
BASE-COLLECTOR	24.0mA	.01mA
BASE-EMITTER	23.4mA	.008mA

Fig. 39-4. Record your results for Step 2 here.

resistors to measure the junction currents. The resistor values were chosen to give reasonable meter indications without affecting the transistor action excessively. By comparing the forward and reverse currents in the chart in Fig. 39-4, you can see that the forward currents are many times the values of the reverse currents for both junctions.

From your regular lessons, you know that forward current across a PN junction is carried out by the majority carriers and reverse current is through minority carriers. Thus the forward and reverse currents you measured in both steps are indicative of the majority and minority carriers respectively crossing the PN junction.

The data accumulated in the chart in Fig. 39-2 can be helpful in checking transistors for condition and type (NPN or PNP). First, you found the resistances across each junction to be high in one direction and low in the other. This indicates that the junctions are neither shorted nor open. Consequently, you can assume that the transistor is not defective.

Second, you found that to forward bias the junctions a negative voltage is applied to the base. This means that the base must be N-type material and the emitter and collector must be P-type material. Therefore, the transistor is a PNP type. It must be remembered that this is only a rough check for transistors.

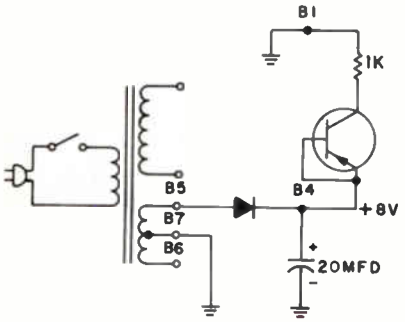


Fig. 39-5. Circuit used for Step 3.

BIAS	COLLECTOR CURRENT
0	.14MA
3V-47K	5MA
3V-10K	6.7MA

Fig. 39-6. Record your results for Step 3 here.

Step 3: To show that base-emitter current can control the emitter-collector resistance.

Construct the circuit shown in Fig. 39-5. Move the anode lead of the silicon diode from terminal B3 to terminal B5. Connect a length of hookup wire from terminal B4 to the emitter terminal of the transistor. Connect a 1,000-ohm resistor from the collector terminal of the transistor to terminal B1. Connect a short length of hookup wire from the emitter to the base terminal.

Energize the circuit and measure the dc voltage across the 1,000-ohm resistor. Convert the reading to current. Since the resistor value is 1,000 ohms, the current in ma is equal to the voltage in volts. This is the collector or collector-emitter current. Record the current in the chart in Fig. 39-6.

Turn the circuit off and connect the 3-volt battery into the base-emitter circuit. Refer to the schematic diagram in Fig. 39-7A. Note that the positive battery lead is connected to the emitter and the negative battery lead is connected

$\frac{2.6V}{10K\Omega}$ $10K\overline{)2.600}$ .26 ma

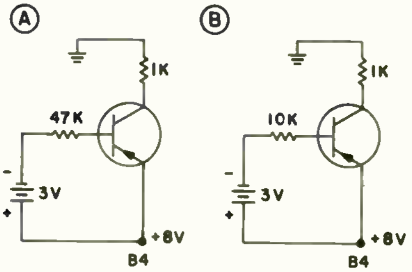


Fig. 39-7. Circuit used for Step 3 and Report Statement 39.

through a 47K-ohm resistor to the base.

When you have finished the wiring changes, energize the circuit and measure the collector current again. That is, measure the voltage across the 1,000-ohm resistor and convert it to current. Record the current value in Fig. 39-6. Turn the circuit off and replace the 47K-ohm resistor with a 10K-ohm resistor. Then, energize the circuit and measure the collector current again. Record the value in Fig. 39-6. Turn the circuit off.

Discussion of Step 3: A transistor is normally operated with a forward bias on the base-emitter junction and reverse bias on the base-collector junction. You had this condition when you connected the battery into the circuit.

Initially, with the base shorted to the emitter, the collector current was low. This indicates that the resistance between the emitter and the collector is high. By connecting the 3-volt battery and the 47K-ohm resistor between the emitter and base, you permitted about 50 μa of current to flow across the emitter-base junction. This base current resulted in a significant decrease in the resistance of the emitter-collector path of the transistor and permitted about 4 ma of collector current to flow.

When you substituted the 10K-ohm resistor for the 47K-ohm resistor, you increased the base current to about 270 μa. The increased base current caused a further reduction in the emitter-collector path resistance, resulting in a substantial increase in collector current.

Before leaving this circuit, note the directions of the currents and the polarities of voltages applied to the junctions in Fig. 39-7B. Because this is a PNP transistor, the base is slightly negative (about .2V) with respect to the emitter. Thus, current flows from the negative side of the battery, through the 10K-ohm resistor to the base. Current crosses the base-emitter junction and flows from the emitter back to the positive side of the battery.

The emitter-collector voltage is applied so that the base-collector junction is reversed biased. In a PNP transistor, this means that the collector will be negative with respect to the base. The primary current path is from the negative terminal of the power supply through the 1K-ohm resistor to the collector. Within the transistor, current crosses the collector-base and base-emitter junctions. From the emitter, the current flows back to the positive terminal of the source voltage.

Instructions for Statement No. 39: For this Report Statement, you will compare the base current and the collector current in the circuit shown in Fig. 39-7B.

Turn the circuit on and measure the current through the 1K-ohm collector load resistance. (You can use the value from Fig. 39-6 if you wish.) Now, move the voltmeter probe and ground clip and measure the voltage across the 10K-ohm base resistor. Using the procedure outlined earlier, calculate the base current.

Now, you have enough data to answer the Report Statement. Answer the State-

Collector 6.7MA
Base .26 ma.

.3)6.0

ment here and on the Report Sheet and turn the circuit off. Also, unsolder and disconnect the 3-volt battery.

Statement No. 39: When I compared the base and collector currents, I found that:

(1) the base and collector currents were about equal.

(2) the base current was slightly greater than the collector current.

[✓ *(3)*] *the collector current was between 20 and 30 times the base current.*

EXPERIMENT 40

Purpose: To demonstrate the fundamentals of voltage regulation and to show the operation of basic shunt and series regulators.

Introductory Discussion: In many electronic applications the voltage supplied to the various circuits must be stabilized (regulated) against variations in load and input voltage. There are a number of different methods used to regulate both high and low voltages. In this experiment we will investigate simple shunt and series regulators in both high and low voltage applications. We will be primarily concerned with regulators which stabilize voltages for variations in *load* current.

The percent regulation of a power supply for load variations is expressed using the following relationship: % regulation =

$$\frac{E_{\text{no load}} - E_{\text{full load}}}{E_{\text{full load}}} \times 100$$

For example, if the no load output of a certain power supply were 110 volts and the full load voltage were 100 volts, the percent regulation would be: % regulation =

$$\frac{110 - 100}{100} \times 100 = \frac{10}{100} \times 100 = 10\%$$

A perfect power supply would have zero percent regulation since the no load and full load voltages would be the same. The larger the percent regulation, the poorer the power supply is said to be regulated.

The basic shunt regulator consists of a series resistance connected between the power supply and the load, and a constant-voltage variable-current device connected in parallel with the load. As the load current varies, so does the current of the shunt regulator to maintain a constant output voltage.

In the basic series regulator, a variable resistance device is connected between the power supply and the load. As the load current varies, the series resistance is changed to keep the output voltage steady. We will examine both shunt and series regulators in this experiment.

Experimental Procedure: For this experiment you will need the experimental chassis, your tvom and the following parts:

1	100-ohm resistor
1	220-ohm resistor
1	1K-ohm resistor
1	2.2K-ohm resistor
1	4.7K-ohm resistor
1	22K-ohm resistor
1	47K-ohm resistor
1	12BA6 tube
1	Neon lamp
2	HV diodes
2	LV diodes
2	20-mfd electrolytic capacitors

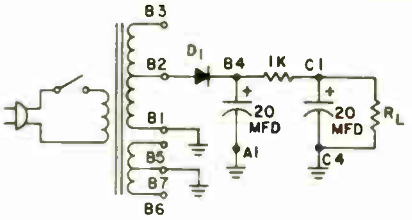


Fig. 40-1. The circuit used for Step 1 and Step 2.

By now you have worked with the experimental chassis enough that you should be familiar with the terminal strips and the schematic symbols used in the diagrams. Therefore we will not give detailed instructions for changing the wiring around for the various steps in this experiment.

Step 1: To measure the regulation of a typical half-wave high voltage power supply.

Construct the circuit shown in Fig. 40-1. Use a high voltage diode for D_1 and be sure to observe the polarity of the two electrolytic capacitors when you connect them into the circuit. The output terminal of the supply is terminal C1. Do *not* connect resistor R_L (the load resistor) yet.

When you have the circuit wired, turn on your tvom and set it to read 120 volts dc. Clip the probe to terminal C1 and the ground clip to the chassis. Turn the circuit on and read the no load output voltage. Record this reading in Fig. 40-2 under "NO LOAD VOLTAGE" for Step 1. Without disconnecting the tvom, turn the circuit off. Notice that the output voltage drops very slowly even though you have turned the power off. This is because the two 20-mfd capacitors are fully charged and are loaded only by the tvom. They would retain this charge quite a long time and if you were to start making circuit changes now you could receive a nasty shock from the "dead" circuit.

To discharge the filter capacitors, take a screwdriver and quickly short terminal C1 to the chassis. This will discharge both of the capacitors. This is *always* a good practice to follow when working with circuits operating at high voltages: With the power off, short the output filter capacitor to discharge it before working on any of the circuits.

With the power supply discharged, remove the tvom probe and solder a 22K-ohm resistor from C1 to C4. This will be your load resistor. Reconnect the tvom probe to C1, turn on the power and

STEP	NO LOAD VOLTAGE	FULL LOAD VOLTAGE	PERCENT REGULATION
1	88V	80V	10
2	83V	77V	7.8
3	47V	30V	56
4	49V	47V	4.2

$\frac{E_{NL} - E_{FL}}{E_{FL}} \times$

Fig. 40-2. Record your results for Steps 1 through 4 here.

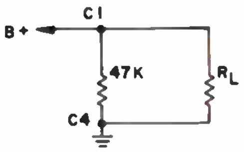


Fig. 40-3. The 47K bleeder used in Step 2.

record the FULL LOAD VOLTAGE for Step 1 in Fig. 40-2. Using the formula given previously, calculate the percent regulation and enter this value in Fig. 40-2. With the tvom still connected to terminal C1 turn the power to the circuit off. Notice that the voltage decreases rapidly to zero with the 22K-ohm load in place.

Step 2: To show that a bleeder resistor will improve the power supply regulation.

By placing a fixed load on the power supply the voltage regulation will be improved. You have demonstrated this before in an earlier Training Kit, but now you will see the bleeder resistor used in a real power supply. You will use a 47K-ohm bleeder as shown in Fig. 40-3. Solder it into the circuit, turn the power on and measure the no load output voltage. Record this in Fig. 40-2 for Step 2. Turn the power off, discharge the filter capacitors and connect the 22K-ohm load resistor as before. Turn the power on and record the full load voltage in Fig. 40-2. Calculate the percent regulation and enter it in Fig. 40-2 also.

Step 3: To show the operation of a basic shunt regulator.

With the power off, wire the neon shunt regulator shown in Fig. 40-4. Do not connect R_L yet. Turn the power on and measure the no load output voltage at terminal C3. Record this value in Fig. 40-2 for Step 3. Turn the power off and discharge the filter capacitors. Connect the 22K-ohm load resistor across the neon lamp, turn the circuit on and measure the full load output voltage. Record this in Fig. 40-2 and calculate the percent regulation. Enter this value in Fig. 40-2 also. Turn the power off and discharge the filter capacitors.

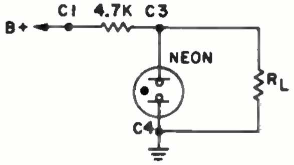


Fig. 40-4. The neon shunt regulator used in Step 3.

Step 4: To show the operation of a basic series regulator.

For this step you will use the circuit of Fig. 40-5. The neon lamp and 4.7K-ohm resistor are already connected. To construct the circuit, install the 12BA6 tube in the socket of the etched circuit board.

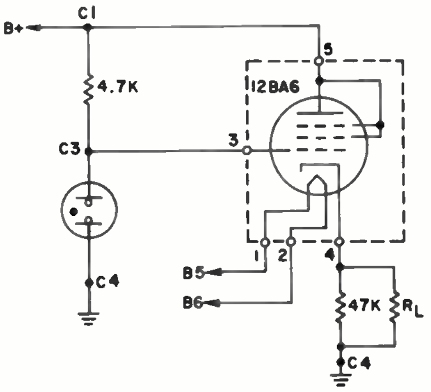


Fig. 40-5. The simple series regulator used in Step 4.

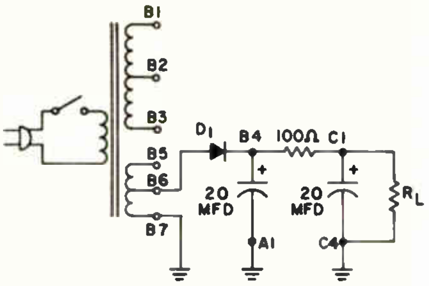


Fig. 40-6. Basic low voltage supply used in Step 5.

Lug 1 and lug 2 should still be connected to terminals B5 and B6. Be sure to remove the 22K-ohm resistor before you connect lug 3 of the circuit board to terminal C3.

When you have wired the circuit, check your connections and turn on the power. It will take a few seconds for the tube to warm up. When the tube has warmed up, read the no load output voltage at lug 4 of the circuit board. Record this value in Fig. 40-2. Turn the power off, discharge the filter capacitors and connect the 22K-ohm load resistor from lug 4 of the circuit board to terminal C4. After allowing the tube to warm up, read the full load voltage at lug 4 of the circuit board. Record this in Fig. 40-2 and calculate the percent regulation. Enter this value in Fig. 40-2 also.

Disconnect the leads and resistors from the etched circuit board and remove the etched circuit board from the chassis. Also remove the 4.7K-ohm resistor and the neon lamp.

You will perform the following steps using the basic low voltage power supply of Fig. 40-6. Disconnect the green lead from terminal B6 and the green/yellow wire from terminal B7. Reconnect the green/yellow lead to terminal B6 and the green lead to terminal B7. To construct the circuit of Fig. 40-6, move the anode lead of D_1 from terminal B2 to terminal B6 and replace the 1K-ohm resistor with a 100-ohm resistor.

Step 5: To measure the regulation of the basic low voltage power supply.

Turn the power on and measure the no load voltage at terminal C1. Use the 12 volt dc range of your tvom. Record your reading in Fig. 40-7. Connect a 2.2K-ohm load resistor from terminal C4 to terminal C1 and read the full load voltage. Record this value in Fig. 40-7 and calculate the percent regulation. Enter this value in Fig. 40-7 also.

The low voltage equivalent of the neon lamp shunt regulator used in Step 3 of this experiment is the Zener diode. We do not have such a diode, but for our purposes we can use a series of forward-biased silicon diodes to perform roughly

STEP	NO LOAD VOLTAGE	FULL LOAD VOLTAGE	PERCENT REGULATION
5	9.3	7.6	22.3
6	1.75	1.73	1.16
7	1.72	1.70	1.18

Fig. 40-7. Record your results for Steps 5 through 7 here.

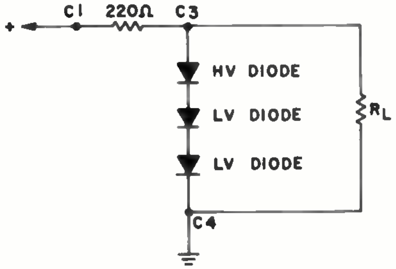


Fig. 40-8. Simple low voltage shunt regulator used in Step 6.

the same job. A forward-biased silicon diode will have a voltage drop of about 0.7 volts if we pass enough current through it. Three diodes connected in series will produce a fairly constant 2.1 volts (3 X .7). You will connect the two low voltage diodes and the remaining high voltage diode in series to make the shunt regulator of Fig. 40-8. Since we will consider the three diodes together as a circuit element, simply tack solder the diodes together: cathode lead of the HV diode to the anode lead of one LV diode; cathode lead of the LV diode to the anode lead of the other LV diode. Solder the anode lead of the diode assembly to terminal C3 and the cathode lead to terminal C4. Connect a 220-ohm resistor between terminals C1 and C3. Terminal C3 is now the output of the low voltage shunt regulated power supply.

Step 6: To see how the basic low voltage diode shunt regulator works.

Turn on the power and measure the no load output voltage at terminal C3. Record this value in Fig. 40-7. Connect the 2.2K-ohm load resistor from terminal C3 to terminal C4 and read the full load output voltage. Record this value in Fig. 40-7 as well as the calculated percent regulation.

Step 7: To show the operation of a transistor series regulator.

Without changing the basic power supply connections, wire the series regulator shown in Fig. 40-9. Notice that now the output voltage is between terminals C1 and C3, and *not* to the chassis. This is necessary to simplify the wiring since the PNP transistor must be placed in the *negative* lead of the power supply. Refer to Experiment 39 if you have forgotten which are the base and emitter terminals of the transistor. After you have completed wiring the circuit of Fig. 40-9, carefully recheck your wiring to be sure all parts and leads are correctly placed.

Clip the probe of your tvom to terminal C1 and the ground clip to terminal C3. Turn the power on and record the no load output voltage in the space provided in Fig. 40-7. Connect the 2.2K-ohm load resistor between terminals C1 and C3, record the full load voltage and percent regulation in Fig. 40-7 and turn off the power.

Discussion: In the first step you measured the regulation of a typical high voltage power supply. You saw how a bleeder resistor, while lowering the no load output voltage, improved the power

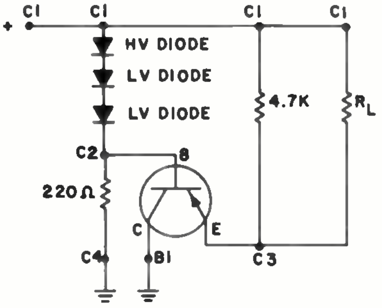


Fig. 40-9. Low voltage series regulator used in Step 7.

supply regulation. Going one step further, you saw how the neon lamp could be used to provide extremely good regulation in Step 3. Neon lamp regulators make use of the characteristics of neon gas that when the gas becomes ionized (by applying a high enough voltage), the voltage drop is very constant and independent of the current through the gas. As a shunt regulator, when the applied load draws current from the supply, the current through the neon decreases but the voltage across it remains constant.

The neon lamp was used as a stable reference voltage for the series regulator of Step 4. The 12BA6, connected as a triode, was used as a cathode follower. The tube supplied cathode current to the load and the neon acted only as a stable reference voltage to set the grid and cathode voltage.

Step 5 and Step 6 were basically similar to Steps 3 and 4 using the low voltage power supply. The series regulator of Step 7 is the transistor equivalent of the circuit used in Step 4. The forward-
1.82 biased diodes provided the reference voltage while the transistor acted as a variable resistance to maintain the output voltage steady with changes in load current.

Instructions for Statement 40: For this Statement you will double the voltage applied to the transistor series regulator of Fig. 40-9 and see how well the circuit regulates input voltage variations.

Leave the 2.2K-ohm resistor connected and move the anode of the rectifier, D_1 from terminal B6 to terminal B5. Turn the power on and measure the output voltage between terminals C1 and C3. Compare this voltage with the full load voltage recorded for Step 7 in Fig. 40-7.

Answer the Report Statement below and on your Report Sheet.

Statement No. 40: When I doubled the voltage applied to the transistor series regulator I found the output voltage:

[✓ *(1)*] *did not change significantly.*
(2) increased considerably.
(3) almost doubled.

WIRING THE PILOT LAMP

This completes your experimental work in this Training Kit. You will now install and wire the neon lamp in its permanent location, where it will serve as a pilot lamp. You will need a 100K-ohm resistor.

Unplug the power cord of the chassis. Push the lamp into the grommet in the front panel from the inside, as shown in Fig. 17, so that about 1/4" projects on the outside of the chassis. Connect the leads to terminals 1 and 2 of strip E but do not solder. Connect and solder a 100K-ohm resistor from terminal 1 of strip E on the front panel to terminal 4 of the on-off switch on the back of the potentiometer.

Connect a length of hookup wire from terminal 2 of strip E to terminal 3 of strip D. (Note: this terminal has a power cord and black transformer lead connected to it.) Solder the connections.

Turn the switch off and plug in the power cord. The neon lamp should not light. If it does, unplug the power cord, unsolder the resistor lead from terminal 4 and solder it to terminal 5 on the back of the switch and plug the cord in again.

Your pilot lamp should then be wired directly across the primary winding of the power transformer. Thus, it will light only when the circuit is energized.

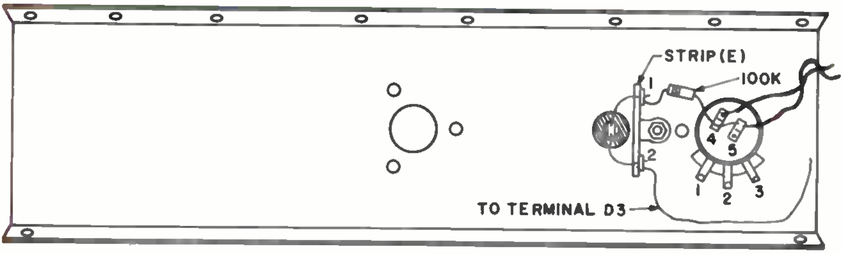


Fig. 17. Pilot light wiring.

LOOKING AHEAD

This completes your experimental work on power supplies. After you have answered all the statements on the Report Sheet, send it to NRI for grading. While you are waiting for your next kit, unsolder and remove all resistors and capacitors wired to terminal strips A, B and C and the circuit board.

Clean the terminals on top of the chassis and on the circuit board. Hold the chassis up and heat the terminals, allowing the solder to run down on the tip of your soldering iron. You should also clean and straighten the leads on your components so they will be usable in your future experiments.

Check the tip of your soldering iron. If necessary file and re-tin the tip, using the procedure given in the first group of experiments.

The parts that are left over are listed in Table I.

1	.1-mfd tubular capacitor
2	.25-mfd tubular capacitors
3	20-mfd electrolytic capacitors
2	1.5V flashlight cells
1	Experimental chassis w/parts attached
1	Etched circuit board w/7-pin tube socket
1	Alligator clip
2	LV silicon diodes
2	HV silicon diodes
1	1K-ohm potentiometer
1	100-ohm resistor
1	220-ohm resistor
1	470-ohm resistor
1	680-ohm resistor
3	1K-ohm resistors
1	2.2K-ohm resistor
1	3K-ohm resistor
1	3.3K-ohm resistor
2	4.7K-ohm resistors
1	6.8K-ohm resistor
1	10K-ohm resistor
1	15K-ohm resistor
1	18K-ohm resistor
2	22K-ohm resistors
1	47K-ohm resistor
2	100K-ohm resistors
1	220K-ohm resistor
1	470K-ohm resistor
1	1-megohm resistor
1	1.8-megohm resistor
2	10-megohm resistors
1	12BA6 tube

Table I. Parts left over after completing the experiments in this kit.

Cashing In On Discontent

Discontent is a good thing -- if it makes you want to do something worthwhile. If you had not been discontented, you would never have enrolled in the NRI course.

Practically everyone is discontented. But some of us are "floored" by discontent. We develop into complainers. We find fault with anything and everything. We end up as sour and dismal failures.

Those of us who are wise use our discontent as fuel for endeavor. We keep striving toward a goal we have set for ourselves. We are happy in our work. We face defeat, and we come out the victors.

At this minute you may be discontented with many things -- your progress with your course, your earning ability, yourself.

Make that discontent pay you dividends. Don't let it throw you down. If you do, you may never be able to get up again. Keep striving to remove the cause of your discontent. Remember that it's always darkest before the dawn. And a real NRI man works hardest and accomplishes most when he is face to face with the greatest discouragements.

139-KM-204(602)

ACHIEVEMENT THROUGH ELECTRONICS

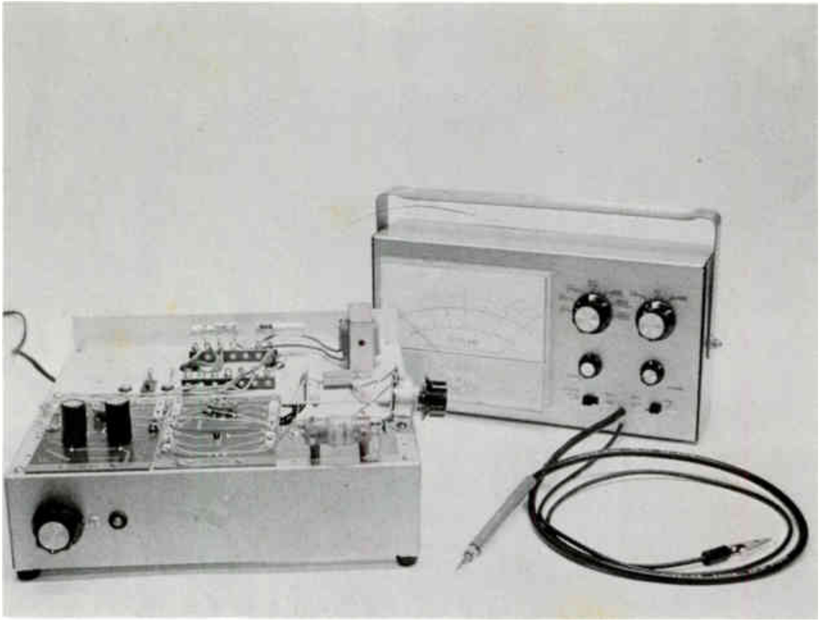
TRAINING KIT MANUAL

5T

NATIONAL RADIO INSTITUTE • WASHINGTON, D. C.

TRAINING KIT MANUAL 5T

PRACTICAL DEMONSTRATIONS OF RADIO-TV FUNDAMENTALS



INDEX OF SECTIONS

NRI4M373 1973 EDITION Litho in U.S.A.

INSTRUCTIONS FOR PERFORMING EXPERIMENTS 41 THROUGH 50

In any modern AM/FM or TV receiver there are only a few basic parts such as resistors, capacitors, inductors (transformers and coils) and amplifying devices (tubes and transistors). You have already conducted experiments using resistors and capacitors that show how they act in ac and dc circuits. Now you are going to demonstrate the action of tube and transistor amplifiers and learn how tubes and transistors can be used in practical circuits.

Although tubes and transistors will do the same job, they work in different ways. For this reason, the basic tube and transistor experiments will be carried out separately.

The first four experiments show how a tube produces signal amplification. After completing this section, you will demonstrate how transistors work and how they can produce amplification.

In the remaining experiments, you will study oscillator circuits and cascade amplifiers. You will show that an oscillator is actually a self-excited amplifier and then you will build up and demonstrate the various types of oscillator circuits. This section includes both L-C oscillators and R-C oscillators.

You will demonstrate both R-C coupled and DC (direct coupled) cascade amplifiers in the final experiment. You will see how the individual circuits work and you will demonstrate how the amplifier stages affect each other. In this experiment you will also get valuable experience in finding defects in practical amplifier circuits.

Each experiment in this manual illustrates some important fact you will need in your servicing career. Study each experiment carefully -- make sure you understand both what you are going to show before you start, and the conclusion drawn from each experiment in the discussion.

CONTENTS OF THIS KIT

The contents of this kit are illustrated in Fig. 1 and listed below it. Check the parts you received against this list to be sure you have all of them. Some of the parts sent to you may be slightly different in appearance from those pictured in Fig. 1.

Do not discard any of these parts or the parts from previous kits until you have finished your NRI course or unless instructed to do so. Do not cut the leads of any part.

IMPORTANT: If any part in this kit seems to be missing, look for a substitute. If any part is obviously defective, or has been damaged in shipment, return it immediately to NRI as directed on the "Packing and Returned Material" slip included with this kit.

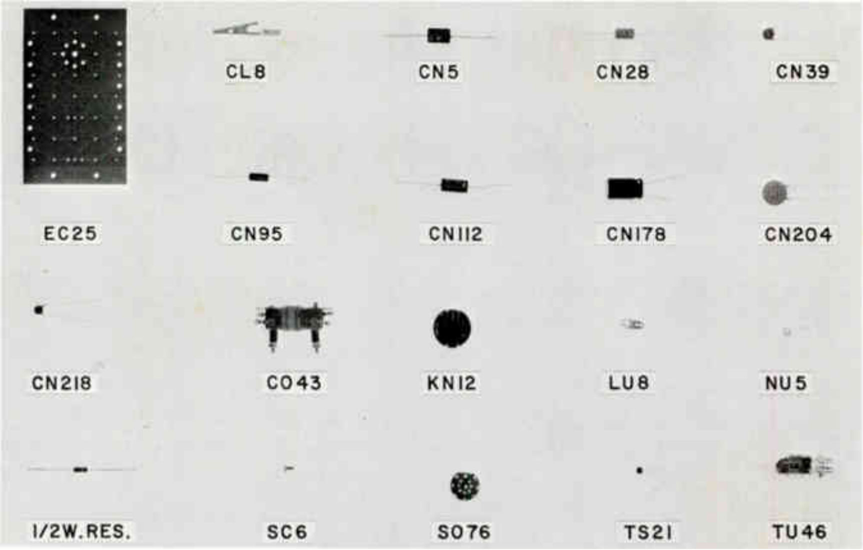


Fig. 1. Parts supplied with this kit are shown above and listed below.

Quan.	Part No.	Description	Price Each
1	CL8	Alligator clip	.07
1	CN5	250-pf mica capacitor	.24
1	CN28	10-mfd, 25V electrolytic capacitor	.59
1	CN39	.002-mfd disc ceramic capacitor	.15
1	CN95	6-mfd, 20V electrolytic capacitor	.42
1	CN112	100-mfd, electrolytic capacitor	.45
2	CN178	200-mfd, 35V electrolytic capacitors	.45
1	CN204	.05-mfd disc ceramic capacitor	.30
2	CN218	.001-mfd disc ceramic capacitors	.15
1	CO43	Oscillator coil	1.17
1	EC25	Experimental etched circuit board	1.10
1	KN12	Bar knob	.17
13	LU8	No. 4 solder lugs	12/.15
16	NU5	4-40 hex nuts	12/.15
1	RE35	47K-ohm, 10%, 1/2W resistor	.15
1	RE45	3.3K-ohm, 10%, 1/2W resistor	.15
1	RE58	2.2K-ohm, 10%, 1/2W resistor	.15
1	RE64	33K-ohm, 10%, 1/2W resistor	.15
1	RE67	68K-ohm, 10%, 1/2W resistor	.15
1	RE72	47-ohm, 10%, 1/2W resistor	.15
1	RE76	10-ohm, 10%, 1/2W resistor	.15
1	RE118	330K-ohm, 10%, 1/2W resistor	.15
1	RE140	330-ohm, 10%, 1/2W resistor	.15
16	SC6	1/4" X 4-40 machine screws	12/.15
1	SO76	7-pin miniature pc tube socket	.12
2	TS21	2N5134 NPN silicon transistors	.19
1	TU46	12AT6 vacuum tube	1.20

THE 12AT6 TUBE

The 12AT6 tube supplied in this kit is really two tubes in one. It consists of a high-gain triode section and a double diode section. The triode and the two diode plates all use the same cathode. The diodes can be used to rectify small signal voltages. Because of their small physical size and close spacing to the cathode, they could not be used to rectify high currents or high voltage as found in a receiver power supply.

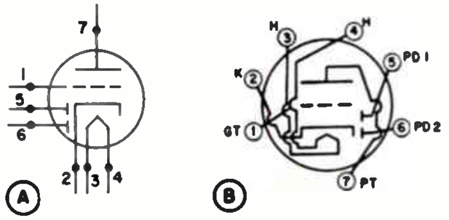


Fig. 2. Schematic symbol for a 12AT6 tube (A) and connections of the elements to the pins (B).

A diagram of a 12AT6 tube showing the elements schematically and the arrangement of the pins is shown in Fig. 2. The standard practice for numbering the tube pins has been followed in this diagram -- that is, it is assumed that you are looking at the base of the tube (or at the bottom of the tube socket). Notice that pin 1 is at the left of the space where there is no pin, and that the numbers increase as you go around the tube clockwise from this pin. This is the numbering system used for all miniature tubes.

Note that the triode grid connects to pin 1, and is marked GT. The cathode is connected to pin 2, and is marked K. The cathode is common to the triode and diode sections. The heater, marked H, connects to pins 3 and 4. The two diode plates are marked PD1 and PD2, and are connected to pins 5 and 6. The triode plate, marked PT, is connected to pin 7.

This tube heater or filament requires an operating voltage of 12 volts at a current of .15 ampere. The maximum plate voltage rating for the triode section of this tube, when it is used as an amplifier, is 300 volts, applied between the triode plate and the cathode. However, in these experiments we will use a voltage of approximately 100 volts.

TRANSISTORS

You received two small junction transistors in this kit. They are low power NPN silicon transistors. Such transistors are normally used as high gain amplifiers for small signals or as oscillators.

Each of these transistors has a base of P-type material and an emitter and collector of N-type material. This is just the opposite of the PNP transistor you used in the preceding kit.

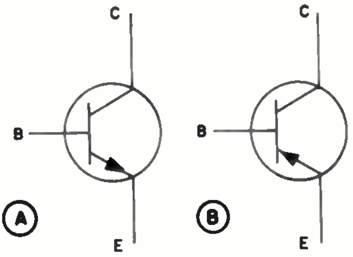


Fig. 3. The schematic symbol for (A) an NPN transistor and (B) a PNP transistor.

The schematic symbols for an NPN and PNP transistor are shown in Fig. 3. Note that the only difference between them is the direction of the arrow. In an NPN transistor symbol, the arrow points away from the base and, in a PNP transistor symbol, the arrow points toward the base.

Because a transistor can be damaged by rough handling or excessive heat, you must be careful with it. This will be discussed further when you connect the transistor into a circuit.

INSTRUCTIONS FOR PERFORMING THE EXPERIMENTS

Each of the experiments described in this manual will contribute to your knowledge of circuit action and develop your skill in handling parts, in making measurements, in adjusting circuits to resonance, and in learning how circuit defects can prevent proper operation. Do not rush through the experiments. Spend enough time on each one to make sure you not only get acceptable results, but also thoroughly understand each principle involved.

The extra practice in soldering you will get as you go through these experiments will be very helpful if you make every effort to make your soldering better each time. But if you are careless, the extra practice will make bad habits harder to break. Remember you need very little solder to make a good connection. The parts must be clean and enough heat must be applied to melt the solder into a smooth flowing liquid and burn off the rosin. If there is rosin in a joint, the poor connection may affect your experiments. After the solder has cooled, test the strength of the connection by pulling the leads gently with a pair of longnose pliers. Even an expert will have trouble soldering with an iron with a pitted, corroded, or untinned tip. A beginner will have more trouble and may not be able to tell if he has a good soldered connection even though the parts seem to be held together. Make it a habit to check the tip of your iron periodically, re-filing it when necessary and keeping it bright and tinned.

To get the greatest benefit from each experiment, make sure you understand the principles and the procedure before you set up the circuits and take your measurements. If any part of the theory involved in the experiment puzzles you, refer to the lesson texts in your course where the principles are covered, and read them carefully.

If you fail to get acceptable results from any experiment, review the instructions carefully. Make sure your tvom is properly calibrated and the 9-volt battery is in good condition. If it is weak, replace it. Make sure that you connect the tvom properly to the experimental circuit. If the ground clip is disconnected from the chassis of the experimental circuit and you touch only the probe to the circuit, you will get erratic readings, which are meaningless.

We shall not give you detailed instructions on the adjustment and use of your tvom in these experiments, so failure to get the proper readings may be caused by some error in your use of the instrument. If you are not absolutely sure that you know every detail of how to adjust and use your tvom, refer to the instructions given in Kit Manuals 2T and 3T.

Examine each experimental circuit to see that you have set it up correctly and have the correct components in the circuit. Then check for possible defective parts and for poorly soldered connections. Also make sure that the power supply furnishes the right plate and filament voltage for the experiment. Be patient and thorough in your search for any trouble that develops.

If you are unable to get the correct

results, or to locate the source of trouble, write to us for help. Use the special Consultation Blank enclosed with this kit. Describe the trouble briefly but completely. Also describe the tests you have made and the results of those tests. Be sure to include the actual values found in any measurements you have made so that we will have facts and figures on which to base our reply.

As you have done in previous kits, record your results in the charts or tables provided, as you perform each experiment. After you have completed each experiment, fill out the Statement at the end of the experiment and on the Report Sheet.

Be sure to turn your experimental equipment and tvom off when you are not performing experiments.

Preliminary Assembly

You will begin to prepare the experimental chassis for the experiments in this kit by assembling and mounting an etched circuit board. Then you will wire the HV power supply you will use throughout this kit.

The diagram in Fig. 4 shows the locations of the holes in the chassis. Refer to it as necessary.

If any resistors or capacitors are still attached to the terminals on top of your chassis, remove them at this time.

WIRING THE CIRCUIT BOARD

To prepare the etched circuit board, you will need these parts.

- **1 Circuit board (EC25)**
- **1 7-pin socket (SO76)**
- **13 Terminal lugs (LU8)**
- **12 1/4" X 4-40 screws**
- **12 4-40 hex nuts**

Mount the tube socket on the foil side of the circuit board as shown in Fig. 5. (Fig. 5 shows the circuit board mounted on the chassis.) Line the pins up over the holes and push the socket down tightly to seat the pins. Then solder the 7 pins to the copper foil.

Attach twelve terminal lugs on the foil side of the board at the places shown in Fig. 5. Attach each lug with a 1/4" X 4-40 screw and nut. Position each terminal so that it does not short to adjacent terminals or strips on the circuit board and tighten the nuts.

Remove circuit board EC24 from the

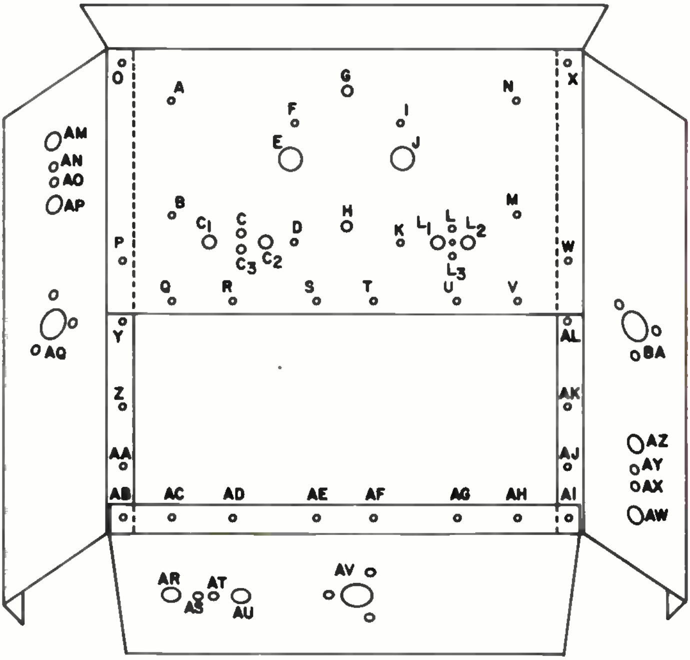


Fig. 4. How to identify the holes in the experimental chassis.

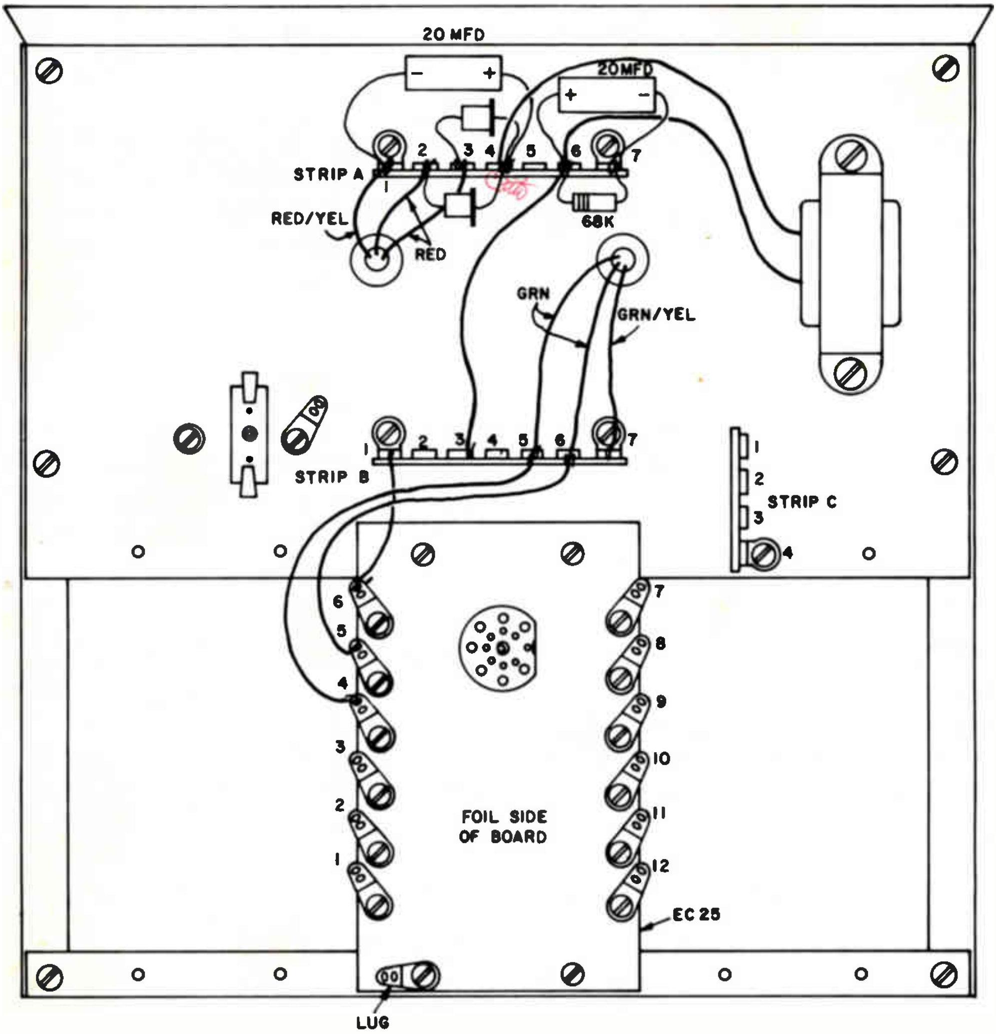


Fig. 5. Pictorial diagram of the circuit board and the preliminary wiring.

experimental chassis and mount the new board, EC25, in its place, as shown in Fig. 5. Attach this board with four 1/4" X 4-40 screws and nuts. Place a terminal lug under the mounting screw at hole AE, as shown.

Refer to Fig. 5 to identify the terminal lugs on circuit board EC25.

Connect and solder a length of hookup wire from terminal B5 to lug 4 on the circuit board.

Connect and solder a length of hookup wire from terminal B6 to lug 5 on the circuit board.

Connect and solder a length of hookup wire from lug 6 to terminal B1.

ASSEMBLING THE HV POWER SUPPLY

The HV power supply will be wired on terminal strip A. You will need the following parts:

- 2 HV silicon diodes
- 2 20-mfd, 150V electrolytic capacitors
- 1 68K-ohm resistor

The diodes and capacitors were left over from the previous kit.

Construct the circuit shown in the schematic diagram in Fig. 6. Fig. 5 also shows the wiring on the chassis. First, unsolder the red and red/yellow power transformer leads from terminal strip B. Connect a length of hookup wire between terminal A6 and B3.

Solder the red/yellow transformer lead to terminal A1. Connect one red transformer lead to terminal A2 and connect the other red lead to terminal A3.

Connect an HV diode between terminals A2 and A4, with the cathode lead to A4. Solder terminal A2.

Connect a second HV diode between terminals A3 and A4, with the cathode lead to A4. Solder terminal A3.

Connect one lead of the filter choke to terminal A4. Connect the other lead of the filter choke to terminal A6.

Connect and solder a 68K-ohm resistor between terminals A6 and A7.

Connect a 20-mfd, 150V electrolytic capacitor from terminal A1 to terminal A4. The positive lead connects to A4. Solder both connections.

Connect another 20-mfd, 150V electrolytic capacitor from terminal A6 to terminal A7, with the positive lead to A6. Solder both connections.

Check your wiring to be sure that the polarities of the diodes and the capacitors are correct and that there are no short circuits. Also, be sure that all connections are soldered.

To test the power supply, short terminals A4 and A6 to the chassis momentarily to discharge the electrolytic capacitors. Then, connect your ohmmeter to measure the resistance between the chassis and terminal A6. Set the range switch to R X 10K, set the polarity switch to normal and touch the probe to terminal A6. You should read at least 40,000 ohms.

If you get this reading, you are ready to test the power supply for voltage. Set the function switch on your tvom to dc and set the range switch to the 120V position. Energize the circuit and measure the voltage. You should read 80 volts or more. If the voltage is negative, the diodes are installed incorrectly; if the voltage is quite low, look for a capacitor or diode installed incorrectly, a poor connection or a resistor of too low a

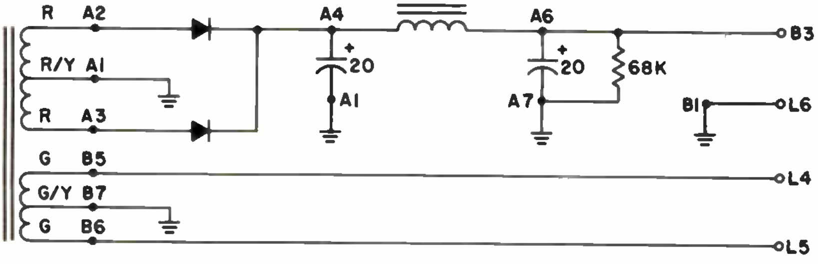


Fig. 6. Schematic of HV power supply.

value between terminals A6 and A7. If you have trouble and cannot locate it, write for help before you go on with your experiments.

You now have a full-wave rectifier circuit operated from the center-tapped high voltage winding of the power transformer. The circuit is quite conventional in all respects. The resistor connected across the output of the filter network is primarily a bleeder resistor. Its purpose is to present a constant load to the power supply and to discharge the filter capacitor slowly when the power is turned off.

Vacuum Tube Fundamentals

The primary function of a triode or other type of tube having a control grid is amplification. Amplification, as you know, is increasing the strength of a signal so it can provide a useful output. An example of this is found in a public address system. The amplifier builds up the weak signal produced by the microphone and makes it strong enough to operate a speaker.

You have already conducted experiments that show that current flows from cathode to plate in a triode and that the amount of current can be controlled by the grid voltage. In the following experiments you will demonstrate bias, biasing methods and practical amplifier circuits.

EXPERIMENT 41

Purpose: To show that a voltage applied to the control grid of a vacuum tube will control the plate current; and to show that the effect the grid voltage has on the plate current depends upon the polarity of the control grid voltage with respect to the cathode.

Introductory Discussion: In a previous experiment you saw that the cathode-plate path of a tube is conductive. When the tube was connected to the source in series with a resistor, the voltage divided between the tube and the resistor. This resistor is called the plate load of the tube, because it is usually in the plate circuit and because it translates variations in plate current into voltage variations.

In these experiments we will not actually measure the plate current flowing through the tube and the load resistor. Checking the voltage drop across the tube or across the resistor will show whether current is flowing, when the current changes, and whether it increases or decreases.

Remember that when the current increases, there will be *less* voltage across the tube and *more* voltage across the plate load resistor. When the plate current of the tube decreases, there will be more voltage across the tube, and less voltage across the plate load resistor.

In a previous experiment, you compared the plate voltage with the grid not connected to anything, and with the grid shorted to the cathode. The resultant change in plate voltage showed that the grid does affect the plate current. In this experiment, you are going to apply voltage between the control grid and the cathode. You will use the two 1.5-volt cells you received in a previous kit. You will be able to make the control grid either positive or negative.

Experimental Procedure: In conducting this experiment, you will need the parts mounted on the chassis, and the following parts:

2	1.5-volt flashlight cells
1	220-ohm resistor
1	100K-ohm resistor
1	12AT6 tube
1	Test clip

After checking your soldering iron tip to be sure it is in good condition, check the condition of the flashlight cells. You have used them in several kits, so you may need to replace them.

To test the two flashlight cells, connect them in series to form a 3-volt battery as you did in previous experiments by connecting a piece of hookup wire from the negative terminal of one cell to the positive terminal of the other. Then set your tvom for dc and measure the voltage of the series-connected cells. The results that you get for this test may show that the cells are good. However, to get a true indication of their condition, you must measure the voltage under load conditions.

To measure the cells under load, connect a 220-ohm resistor between the positive and negative terminals of the series-connected cells. Measure the voltage across the resistor; it should be at least 2.5 volts. If it is not, you will have to obtain new flashlight cells to do this experiment.

When you are sure you have good flashlight cells, unsolder the resistor from the cell terminals, but leave the cells connected in series. Then, put a rubber band or tape around the two cells to hold them together. Lay them on your work surface near the chassis. Cut off about ten inches of hookup wire, solder one end to the ends of the cells that are joined together. This is the positive terminal of one cell and the negative terminal of the other. Solder the free end of this wire to terminal B7.

Connect and solder a 100K-ohm resistor from terminal B3 to lug 8 on the circuit board.

Solder a 10-inch length of hookup wire to lug 7 on the circuit board. Remove about 1/2 inch of the insulation at the other end. The circuit is now wired as in Fig. 41-1. You are now ready to conduct the experiment.

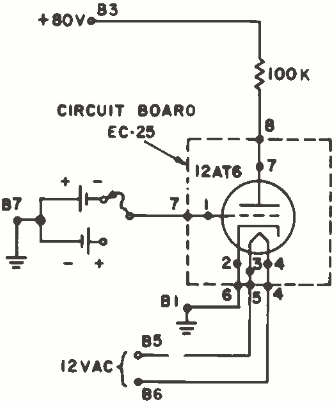


Fig. 41-1. The circuit used in Step 1.

Carefully install the 12AT6 tube in the tube socket. Do not push too hard when you install it or you may break the circuit board.

Step 1: To measure the plate voltage with zero voltage on the control grid.

Set up your tvom for dc voltage measurements; clip the ground lead to the experimental chassis. Slip the test clip which you received in Kit 2T over the probe of the tvom. Clip the probe to lug 8. Turn the circuit on and hold the free end of the tube grid lead against the chassis. This will ground the circuit.

After the tube heats up, observe the voltage reading at the plate. Record the reading in Fig. 41-2.

Step 2: To measure the plate voltage with +1.5 volts applied to the control grid of the tube.

5.00
.35
4.65

STEP	MEASUREMENT	VALUES
1	PLATE VOLTAGE WHEN GRID VOLTAGE = 0	5V
2	PLATE VOLTAGE WHEN GRID VOLTAGE = +1.5V	.35V
3	PLATE VOLTAGE WHEN GRID VOLTAGE = −1.5V	55V
4	CHANGE IN PLATE VOLTAGE WHEN GRID VOLTAGE = +1.5V	[illegible] -4.65
5	CHANGE IN PLATE VOLTAGE WHEN GRID VOLTAGE = −1.5V	+50V

Fig. 41-2. Record your results for Exp. 41 here.

Connect the free lead from the control grid to the positive terminal of the 3-volt battery. This will put a positive voltage of 1.5 volts between the control grid and the cathode. Measure the plate voltage and record your reading for Step 2 in Fig. 41-2.

The plate voltage should have dropped considerably, showing that the application of a positive voltage between the control grid and the cathode of the tube has reduced the resistance in the cathode-plate path of the tube, increasing the plate current, and increasing the voltage drop across the plate load resistor.

Step 3: To show the plate voltage when −1.5 volts is applied between the control grid and the cathode.

Move the free control grid lead to the negative terminal of the 3-volt battery and measure the plate voltage. Record your reading in the space provided for Step 3 of Fig. 41-2. In this case, the negative voltage between the control grid and the cathode has increased the resistance in the path between the cathode and the plate of the tube. This reduces the plate current and sharply reduces the voltage drop across the plate load resistor.

Turn your equipment off.

Step 4: To calculate the change in plate voltage when the grid is made 1.5 volts positive.

Subtract the plate voltage in Step 2 from the value you obtained in Step 1, when the grid was at zero potential. For example, suppose the voltage measured in Step 1 was 11 volts and in Step 2, 1 volt. By subtracting 1 volt from 11 volts, we find that the voltage between the plate and cathode of the tube decreased 10 volts. Compute the change in plate voltage using your readings, and record it in the space provided in Fig. 41-2. Indicate the decrease by placing a minus sign in front of your value.

Step 5: To find the change in plate voltage when the control grid has −1.5 volts applied between it and the cathode.

In this case, subtract the voltage in Step 1 from the voltage in Step 3. Indicate this increase in plate voltage by placing a plus sign (+) in front of your value for Step 5 in Fig. 41-2.

Discussion: The results shown in Steps 4 and 5 in Fig. 41-2 show that a positive voltage applied to the control grid does not cause as much change in the plate voltage as does an equal amount of negative voltage applied to the control grid.

If we were to apply a signal such as a sine wave between the grid and the cathode of the tube under these conditions, the resultant signal across the plate load would be highly distorted, because the negative portion of the signal voltage would be amplified far more than the positive portion.

In the next experiment, we will see how the circuit can be modified to give more linear amplification. By this we mean that a change in grid voltage in a positive direction will cause the same amount of change in the plate voltage as an equal grid voltage change in the negative direction. It is these changes in voltage across the plate load that represent the amplified signal.

Instructions for Statement No. 41: For this Statement you will increase the dc voltage between the grid and the cathode to 3 volts negative, and note the effect on the plate current.

To do this, unsolder the lead that goes from the junction of the two cells to terminal B7, and connect it to the free positive terminal at the other side of one of the cells. Solder the lead from the control grid, lug 7, to the free negative terminal of the other cell. This gives the circuit shown in Fig. 41-3, with 3 volts negative between the control grid and the cathode. Leave the tvom probe clipped to circuit board terminal 8. Connect the ground lead of the tvom to the experimental chassis. Now, turn on the power supply, and give the tube time to heat up.

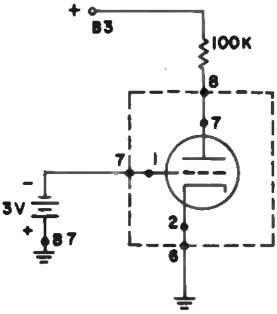


Fig. 41-3. The circuit for Statement 41.

Note the voltage reading on the tvom in the margin of this page. Then, while looking at the meter pointer, grasp the tube lightly, and pull it straight up out of its socket. Note the change in reading when the tube is removed. A slight flicker of 1 or 2 volts can be considered as no change at all. You now have sufficient information to answer the Statement here and on the Report Sheet. Unsolder the lead from the negative battery terminal and turn your circuit and your tvom off.

Statement No. 41: I found that with −3 volts applied between the control grid and the cathode, the cathode-plate path of the tube became, for all practical purposes:

[✓ *(1)*] *an open circuit.*
(2) a low-resistance circuit.
(3) a medium-resistance circuit.

EXPERIMENT 42

Purpose: To show that we can get linear amplification in a vacuum tube by applying a suitable negative voltage to the control grid; and

To show that the tube reverses the phase of the grid voltage 180°.

Introductory Discussion: In the last experiment, the plate voltage variation when the control grid was made 1.5 volts positive was quite different from the plate voltage variations when the grid was made 1.5 volts negative. We said the operation of the tube was nonlinear and a signal voltage amplified by such a circuit would be distorted. When the variations in plate voltage caused by applying positive and negative voltages to the control grid are approximately equal, we say that the tube operation is linear. A signal amplified by this circuit will have the same wave shape as the applied signal. Nonlinear operation of an amplifier tube, therefore, can result if incorrect voltages are applied to the electrodes.

If a negative voltage of the correct value, called a "bias", is applied to the grid, and then varied by a signal, the variations in plate current and plate voltage will be linear. That is, when the control grid is kept negative at all times, a signal that shifts the bias in a positive direction (toward zero) will cause a definite decrease in plate voltage. A signal that shifts the bias in a more negative direction (away from zero) by the same amount will cause an equal increase in plate voltage.

In this experiment, you will vary the grid voltage by using a 1K-ohm potentiometer as a voltage divider across a 3-volt battery. The midpoint of the battery will be grounded and connected to the cathode as shown in Fig. 42-1. By changing the potentiometer setting, you can then make the grid 1.5 volts negative, 1.5 volts positive, or any value in between.

In conducting the experiment, you will find that changing the grid voltage in one direction changes the plate voltage in the opposite direction. Thus, if the grid is made more negative, the plate voltage will increase (become more positive). If the grid is made less negative, the plate voltage will decrease (become less positive). When the tube is properly biased, equal grid voltage variations of opposite polarities will cause plate voltage variations that are approximately equal in magnitude.

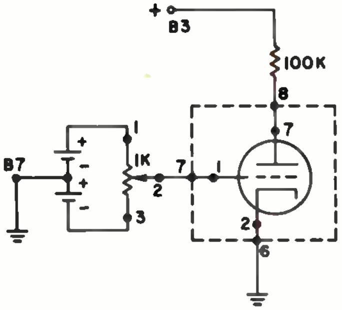


Fig. 42-1. The circuit for varying grid bias.

The exact plate voltage variation that you will obtain will depend upon the characteristics of your tube, the care with which you set the grid bias values and take your readings, and the accuracy with which you have adjusted the zero set on your tvom.

Turn on your tvom a few minutes before you start your work. Then, if you make the zero adjustment just before you start taking measurements, the calibration should not drift. Observe the meter pointer zero position each time before you take measurements and, if necessary, readjust the zero so your results will be as accurate as possible.

When measuring the bias voltages, you will use the 3-volt range of the tvom. The function switch will be set for dc and you will have to switch polarities. When measuring plate voltages, be careful to change the range switch to 120 volts and to see that the polarity switch is set to normal. You can reduce the range selector setting when making plate voltage measurements if necessary.

If you forget and measure plate voltage with the range switch on the 1.2 or 3-volt range or the polarity switch at reverse, the meter pointer will slam off the scale. This may damage your meter so you should train yourself to avoid such carelessness. Always have a good idea of what you are going to measure and always check the tvom switch settings before touching your probe to the circuits.

Experimental Procedure: To conduct this experiment, you will use the tvom, the experimental chassis with the HV power supply and circuit board mounted, and the following parts:

1 Potentiometer mounting bracket
1 3/8" X 6-32 screw
1 6-32 nut
1 No. 6 lockwasher
1 1K-ohm potentiometer
1 Pointer knob

The 100K-ohm resistor should already be connected between terminal B3 and pin 7 of the tube. Wire should be connected from the control grid lug (lug 7) and from the positive terminal of the 3-volt battery to the chassis.

Attach the potentiometer mounting bracket to the right front corner of the chassis at hole AJ. Turn the bracket so that it faces away from the chassis. Attach the bracket with a 6-32 screw, lockwasher and nut. Now, mount the 1K-ohm potentiometer in the bracket with the shaft to the right. Position the potentiometer so that its terminals point upward and tighten the nut.

Rotate the shaft of the 1K-ohm potentiometer fully counterclockwise and attach a pointer knob. The knob is held by a setscrew. If necessary, loosen the setscrew with a small screwdriver. Install the knob in the "7 o'clock" position and tighten the setscrew.

Now you are ready to construct the circuit shown in the schematic diagram in Fig. 42-1. Connect the free end of the lead from lug 7 to the center terminal of the 1K-ohm potentiometer. Cut two pieces of hookup wire about 12 inches long and connect these leads to the two outside terminals of the 1K-ohm potentiometer. The leads will be long enough to reach the positive and negative terminals of the two cells when the cells are lying on your workbench.

The flashlight cells should still be connected in series. If you mistakenly removed the wire joining them, replace it. Connect the hookup wire from terminal B7 to the junction of the two cells. Connect the free end of the wire from one terminal on the potentiometer to the positive terminal of the 3-volt battery, and the free end of the lead from the other terminal of the potentiometer to the negative terminal of the 3-volt battery.

Plug the power cord into an ac wall outlet, and turn on the power supply and let the tube warm up.

Step 1: To measure the plate voltage with 0 volts applied to the control grid.

Connect the ground clip of the tvom to the experimental chassis, set the function switch to dc, and the range selector switch to 3 volts. Touch the probe to the control grid circuit of the tube at lug 7 of the circuit board.

With the probe in place, adjust the knob on the potentiometer until the meter registers exactly 0 volts. Remove the probe, and turn the range selector switch to the 120-volt range.

If the meter pointer is no longer at zero, readjust the zero control. For exact readings, you should check this adjustment on each measurement. In service work, the error introduced by a slight shift in the meter pointer from zero can usually be ignored.

Now touch the probe to circuit board lug 8 and read the meter. If necessary, switch to a lower range. Record the plate voltage in the space for Step 1 in Fig. 42-2.

In the previous experiment you measured the plate voltage with +1.5 and −1.5 volts applied to the grid. You will use smaller positive and negative voltages in the next two steps to see if there is any improvement in the linearity of the output (plate) voltage variations.

Step 2: To measure the plate voltage when the grid voltage is +.5 volt.

Following the same procedure as in Step 1, set the control grid voltage to +.5 volt, measure the plate voltage, and record the value in the appropriate column in Fig. 42-2.

STEP	GRID VOLTAGE	PLATE VOLTAGE	GRID VOLTAGE CHANGE	PLATE VOLTAGE CHANGE
1	0	12V		
2	+.5V	4V	+.5V	+8V
3	−.5V	20V	−.5V	+16
4	−.75V	40V		
5	−.25V	20V	+.5V	20V
6	−1.25V	60V	−.5V	20V

Fig. 42-2. Record your results for Exp. 42 here.

The change in grid voltage was +.5 volt. This has already been recorded in the table. Now, to find out how much the plate voltage changed when the bias was +.5 volt, subtract the plate voltage value you obtained in Step 2 from the value you measured in Step 1. Record it in the last space for Step 2 in Fig. 42-2. Since it is a decrease, put a minus sign in front of it.

Step 3: To measure the plate voltage when the grid voltage is −.5.

Set the grid voltage to −.5 volt, measure the plate voltage, and record it in Fig. 42-2. Be certain to set the switches on the tvom to the proper positions when making these measurements. When measuring a negative grid voltage, set the polarity switch to reverse. Set it to normal for the plate voltage measurement.

In this step, the change in grid voltage was −.5 volt. Find the difference between the plate voltage for Step 1 and the plate voltage for Step 3. Record it in the correct space in Fig. 42-2. Since it is an increase, put a plus sign in front of it.

The change in plate voltage recorded in Step 2 would be as great as the change you recorded in Step 3 if it were not for the fact that the control grid in Step 2 was positive. When the grid is made positive with respect to the cathode, some of the electrons will be attracted to the grid instead of flowing past it to the plate. This, of course, prevents as much decrease in the resistance between the cathode and plate as would be expected, and, as you noticed in Steps 2 and 3, the plate voltage does not vary in step with the grid voltage.

In the remainder of this experiment,

you will see what happens when we use a negative bias at all times, and vary it .5 volt in each direction.

Step 4: To measure the plate voltage when –.75 volt is applied to the control grid.

Adjust the potentiometer so that exactly –.75 volt is applied to the control grid. Then measure the resultant plate voltage. Record the reading in Fig. 42-2.

Step 5: To measure the change in plate voltage when the control grid is driven .5 volt positive from –.75 volt to –.25 volt.

Set the bias to –.25 volt and record the value in Fig. 42-2. Here we are using –.75 volt as the reference value. By decreasing the grid bias from –.75 volt to –.25 volt, we have made the grid less negative (more positive) by +.5 volt. For this reason, we placed a plus sign in front of the grid voltage change in Fig. 42-2. The change is in the positive direction, but the voltage actually applied to the grid is still negative.

Notice that driving the grid voltage .5 volt in a positive direction causes the plate voltage to decrease. Subtract the plate voltage in Step 5 from that in Step 4, and record it in Fig. 42-2. Put a minus sign in front of it to show that the voltage has decreased.

Step 6: To measure the plate voltage when the control grid is driven .5 volt negative, from –.75 volt to –1.25 volts.

Set the bias to –1.25 volts, measure, and record the plate voltage. To find the change in plate voltage caused by a –.5 volt change in grid voltage, subtract the plate voltage in Step 4 from that in Step 6. Record the change in Fig. 42-2. Since the plate voltage increased in this step, put a plus sign in front of it. Turn the circuit off.

Notice that the change in Step 5 is opposite in polarity to that in Step 6, and that the changes are more nearly equal in magnitude than those in Steps 2 and 3. Your readings in Steps 5 and 6 may not be exactly equal. The variations are due to the characteristics of the tube, how accurately you have read your meter, the accuracy with which you set the bias values, and the accuracy of your tvom zero set adjustment. Do not worry about small variations. The important thing is that you see that the values are nearly the same.

Discussion: You have proved in this experiment that when a suitable negative bias is applied to the control grid, the tube operation will be linear, as indicated by the values of plate voltage change in Steps 5 and 6. When you varied the bias voltage an equal amount on either side of the reference voltage value of –.75 volt, the plate voltage changed by an equal amount.

The bias applied to the grid in this experiment was a dc voltage, and the plate voltage was also dc. In a receiver, however, an ac signal is applied in series with the dc bias; the result is a pulsating dc grid voltage that never becomes positive. A large pulsating dc voltage appears in the plate circuit. Thus, the pulsating portion of the dc plate voltage is the amplified signal.

We can show the effect the grid voltage has on the plate voltage by studying the signal waveforms in the output of an amplifier stage. At A in Fig. 42-3 we have

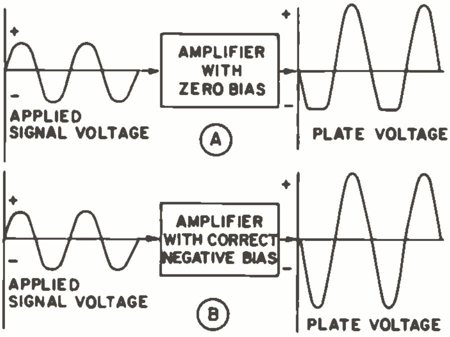


Fig. 42-3. Incorrect bias in a tube causes distortion of the signal, as shown at (A). When the bias is correct, all parts of the signal are amplified the same amount, and no distortion is introduced, (B).

shown a signal voltage applied to an amplifier with zero bias. We have not drawn the schematic of the amplifier, but have merely represented it by a box. To the right of the amplifier, we have shown the resultant variation in plate voltage. Notice that the plate-voltage swing in the negative direction is not as large as the plate-voltage swing in the positive direction. However, the signal in the plate circuit is definitely larger than the grid-voltage variations, indicating that the signal has been amplified. The wave shape at the output of the stage, as you can see, is quite different from that applied to the grid. Thus, the output signal is distorted.

At B in Fig. 42-3, we have shown the same signal voltage applied to an amplifier using the correct negative bias on the control grid. Note that again the plate-voltage variations are larger than the grid-voltage variations, showing that amplification has taken place. This time, the two halves have been amplified the same amount. The tube has amplified the signal without introducing distortion.

From this you can see that correct bias is necessary to avoid distortion. Thus, when the signal at the output of an amplifier stage is distorted, one of the first things you would look for is incorrect bias voltage. In a later kit you will actually hear the distortion introduced by incorrect bias voltage and learn the probable causes of incorrect bias in typical circuits.

In this experiment you have also proved that changing the control grid voltage in a positive direction causes the plate voltage to change in a negative direction. Changing the control-grid voltage in a negative direction drives the plate voltage in a positive direction.

Study the results that you obtained for Steps 5 and 6 in Fig. 42-2. In Step 5, with +.5 volt applied, the direction of the output voltage swing was negative. In Step 6, the grid voltage was −.5 volt. The plate-voltage swing then was in the positive direction.

Thus, a tube connected as shown in Fig. 42-1 reverses the phase of the voltage applied to the control grid by 180°.

This is of no importance as far as the amplification of the signal is concerned. However, it is of real importance in the overall design and operation of radio and TV receivers, as you will later demonstrate.

Instructions for Statement No. 42: For this Statement, you will operate the tube −2 volts on the control grid. Again change the grid voltage .5 volt positive and .5 volt negative and notice the change in plate voltage. To make the change, disconnect the ground lead from the junction of the two cells, and connect it to the positive terminal of the 3-volt battery. The lead from one terminal of the potentiometer should already be connected to this battery terminal.

10

82
72V
84V

Set the bias to −2 volts, and measure the plate voltage. Note the value in the margin of this page. Change the bias to −1.5 volts, and again measure the plate voltage, and make a note of the value. Finally, set the bias to −2.5 volts and measure the plate voltage. Calculate the change in plate voltages as you did previously, and answer the Statement here and on the Report Sheet.

Turn off the supply and disconnect the 3-volt battery from the circuit. The easiest way is to unsolder the leads from the terminals of the potentiometer and the lead from terminal B7. Set the battery aside for use in a later experiment. Unsolder the hookup wire from terminal 2 of the potentiometer.

Statement No. 42: With a −2 volt bias on the grid, I found that when I changed the bias .5 volt in the positive and negative directions, the resultant plate voltage variations were:

(1) more linear than
[✓ *(2) less linear than*]
(3) about the same as

the variations with a bias of −.75 volt.

EXPERIMENT 43

Purpose: To demonstrate the methods of obtaining bias voltage without using a separate battery.

Introductory Discussion: Bias voltage is essential for any amplifier stage which must amplify without excessive distortion. However, a separate bias battery is not normally used in modern circuits, although a separate negative voltage supply is still used in some special-purpose applications. In receivers, bias is obtained from the signal, the amplifier circuit itself or from the B power supply.

The four primary biasing methods are: conduction bias, self bias (cathode bias), fixed bias, and grid-leak bias. You have studied all these methods in your regular lessons. Conduction bias relies on the random movement of electrons within the tube while self bias is produced by tube-plate current flow. Fixed bias uses a voltage divider across the B power supply. Grid-leak bias, on the other hand, is derived from the input signal to an amplifier stage.

Experimental Procedure: For this experiment, you will need the following parts in addition to those mounted on the chassis:

2	**1K-ohm resistors**
1	**3.3K-ohm resistor**
1	**47K-ohm resistor**
1	**10-megohm resistor**
1	**100K-ohm resistor**
1	**.1-mfd capacitor**
1	**3-volt battery**

Before starting work on the new circuits, clean the chassis wiring and remove excessive solder from the terminal lugs.

The circuit you will build for the first step in this experiment is shown in Fig. 43-1. The 100K-ohm resistor is already in the circuit, so all you need to do is

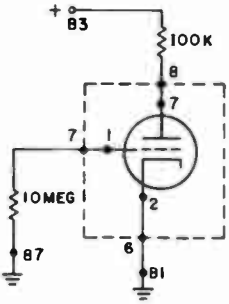


Fig. 43-1. Amplifier using conduction bias.

connect the 10-megohm resistor from the grid of the tube to ground. To do this, connect the resistor from lug 7 to terminal B7.

Step 1: To demonstrate conduction bias.

Connect the tvom ground clip to the chassis, and touch the probe to lug 7. Set the polarity switch to reverse, and the range switch to the 1.2-volt range. Turn on the power supply, and watch the meter. As the tube heats up and the space charge builds up around the cathode, the voltage across the 10-megohm resistor, which is the grid bias, will gradually rise to −1 volt or a little more.

Now, to show that the bias is independent of the B supply, you will open the plate circuit. Turn off the power supply, discharge the filter capacitor, and unsolder the 100K-ohm plate load resistor from terminal B3. Turn on the power supply again and note, when the tube warms up, the bias voltage is still there.

Still watching the meter, grasp the tube and remove it from its socket. You will see that the voltage drops to zero, showing that the bias is dependent on the presence of the tube in the circuit.

Turn off the power supply, and after discharging the filter capacitors, replace the tube in its socket. Resolder the 100K-ohm resistor to terminal B3.

Step 2: To demonstrate self bias.

The circuit used in this step is shown in Fig. 43-2. To construct the circuit, remove the 10-megohm resistor and replace it with a 47K-ohm resistor. Next, connect a 3.3K-ohm resistor in the cathode circuit. Unsolder and remove the short length of hookup wire between lug 6 on the circuit board and terminal B1 and replace it with the resistor.

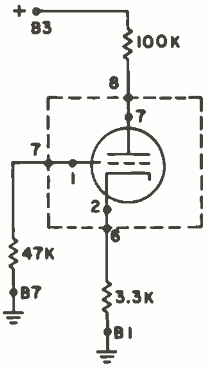


Fig. 43-2. Circuit using self bias.

Switch the tvom to the 3-volt range, connect the ground clip to the chassis and touch the probe to circuit board lug 7. The meter is connected to measure the grid voltage. Turn on the circuit, let the tube warm up and note that there is practically no voltage on the control grid.

Now, to measure the voltage drop across the 3.3K-ohm cathode resistor, touch the probe to lug 6 of the circuit board. Read the meter. Next connect the ground clip to circuit board lug 6 and touch the probe to lug 7. You are measuring grid voltage with respect to the cathode. You should get a negative reading. The voltage between the grid and cathode (pins 1 and 2 of the tube) should be approximately the same as the voltage between the chassis and the cathode lug 6.

To show that the voltage across the cathode bias resistance varies with the plate current, move the tvom ground clip to the chassis and clip the probe to lug 6. Turn the circuit on and observe the meter indication.

Next, apply +3V to the grid. Hold the

negative lead of the 3-volt battery against the chassis and touch the positive lead to lug 7 on the circuit board. Note that when you make the grid positive, the cathode bias voltage increases. Reverse the battery connections to place the negative 3 volts on the grid. Note that this reduces the cathode bias voltage to nearly zero.

Step 3: To show fixed bias.

Turn your circuit off and connect a 100K-ohm resistor between terminal B3 and lug 6. This gives you the circuit shown in Fig. 43-3.

Apply power and measure the voltage between the cathode (lug 6) and the chassis ground. Remove the tube from its socket and note that the voltage does not change significantly. Re-insert the tube. As you did in the preceding step, apply a positive 3 volts to the grid and note that there is very little change in the cathode voltage. Turn the circuit off and discharge the filter capacitors.

Step 4: To demonstrate grid-leak bias.

Unsolder and remove the 3.3K-ohm and 100K-ohm resistors connected to lug

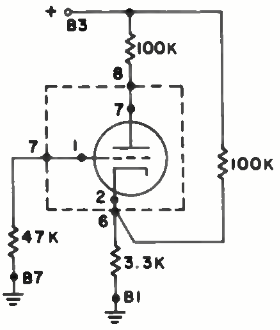


Fig. 43-3. Circuit using fixed cathode bias.

6. Connect a short length of hookup wire between lug 6 on the circuit board and terminal B1.

Connect a .1-mfd capacitor from lug 7 to terminal B6. Set the tvom to read −12V dc and apply power to the circuit. 3.5 V Allow time for warm-up and measure the voltage between the chassis and lug 7. Jot down the value in the margin of this page.

While observing the meter, remove and re-insert the tube. You should see the bias fall to zero whenever the tube is removed from the socket.

Discussion: You have demonstrated the principal methods of obtaining bias voltages for vacuum tube circuits. In the first step, you saw that conduction bias can be produced simply by using a high-value grid resistor. The maximum bias voltage which can be developed, however, is very low, so this method is only used for small amplifier stages. Cathode bias, or self bias, is produced by connecting a resistor in series with the tube cathode. Plate current flows through the resistor and develops a voltage drop across it. This makes the cathode positive with respect to B– or ground. The grid resistor is returned to ground and this places the grid at zero or ground potential. Therefore, the grid is negative with respect to the cathode.

A bypass capacitor can be connected in parallel with the cathode bias resistor to prevent the bias level from varying widely with variations in the signal. With a suitable capacitor, the cathode will remain at an average bias level.

In Step 3, you used fixed bias on the cathode. The 3.3K and 100K-ohm resistors formed a voltage divider across the supply voltage. The voltage drop across the resistor connected between the cathode and ground was the positive cathode bias voltage. The bias level was set primarily by the ratio of the resistor values, although it was increased somewhat by the tube cathode current.

Fixed bias is sometimes applied to the control grid instead of the cathode of the tube. A negative voltage obtained from a separate power supply or by modifying the B power supply is fed to the return side of the grid resistor.

Grid-leak bias, which you demonstrated in Step 4, derives bias voltage from the signal applied to the control grid. The cathode and grid of the tube act as a diode. The grid becomes positive on the positive part of each ac cycle and draws current. This current charges the coupling capacitor connected to the grid.

When the input signal swings in a negative direction, the grid-cathode conduction ceases and the capacitor begins to discharge. Current flows down through the grid resistor to ground and back through the source to the other plate of the capacitor. A negative bias voltage is thus developed at the grid, because the capacitor charges through the low resistance cathode-grid path of the tube and discharges through the large grid resistor.

Instructions for Statement No. 43: For this Report Statement, you will reduce the level of the 60-cycle ac signal applied to the grid and note the effect on the grid-bias voltage.

Disconnect the lead of the .1-mfd capacitor from terminal B6.

Connect two 1K-ohm resistors together to form a 2,000-ohm resistor. Solder one lead to terminal B6 and solder the other lead to terminal B7. These resistors form a voltage divider with about one-half the applied voltage existing between the junction of the two resistors and ground.

Energize the circuit and connect your tvom to measure negative dc voltage at the control grid, lug 7. Touch the free lead of the .1-mfd capacitor to terminal 3.5 B6. Read the bias voltage and jot down the value in the margin.

Now move the capacitor lead from terminal B6 to the junction of the two 1K-ohm resistors. This gives you an input signal of about 3V ac. Measure the grid voltage again. Compare the bias voltage in the two cases and turn your equipment 2 ✓ off. Answer the Statement here and on the Report Sheet.

Statement No. 43: When I reduced the signal level by one-half, the grid-leak bias voltage:

(1) increased by about one-half.
[✓ *(2) decreased by about one-half.*]
(3) remained the same.

EXPERIMENT 44

Purpose: To compare the grounded-cathode, grounded-grid and grounded-plate (cathode follower) types of vacuum tube amplifiers.

There are three different ways of applying a signal and removing the amplified signal from an amplifier stage. These are shown in Fig. 44-1.

The circuit shown at A is known as a "grounded-cathode" amplifier, the one at B a "grounded-plate"amplifier, and the one at C a "grounded-grid" amplifier.

The grounded-cathode circuit is the one most often used in radio and TV amplifier stages. The input signal is applied between the grid and ground, and

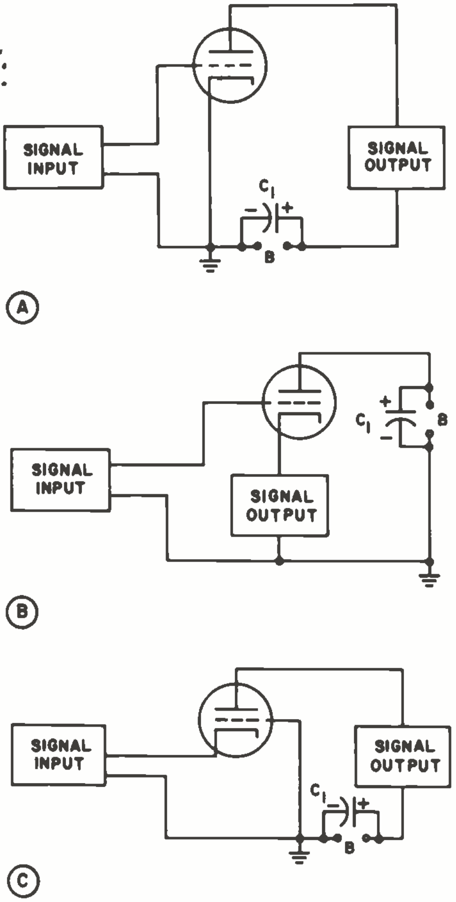


Fig. 44-1. Three types of amplifiers. (A) grounded-cathode amplifier; (B) grounded-plate amplifier; (C) grounded-grid amplifier.

the output is taken off between the plate and ground. The cathode can be connected directly to ground, or it can be grounded through a resistor. If a bias resistor is used between the cathode and ground, the resistor is generally bypassed with a capacitor. The impedance of the capacitor at the signal frequency is so low that practically no signal voltage is developed between the cathode and ground. Thus, the cathode is at ground potential as far as the signal is concerned.

In some cases, the cathode bias resistor is left unbypassed so an ac voltage is developed between the cathode and ground, which acts to reduce the signal voltage between the control grid and the cathode. The effect is the same as if a smaller signal voltage were being used, and the signal output is reduced. This effect is known as degeneration and is often deliberately introduced to stabilize amplifiers, to prevent oscillation, or to reduce distortion. However, this ac voltage is relatively low, and the circuit is still considered a grounded-cathode amplifier.

In the grounded-plate amplifier as shown at B in Fig. 44-1, the plate is kept at a high dc potential so it will attract electrons from the cathode. The plate, however, is bypassed by capacitor C_1 so that as far as the signals are concerned, the plate is at ground potential. Capacitor C_1 could be the output filter capacitor in the power supply.

The signal is applied between the grid of the tube and ground, as in the grounded-cathode type. However, the output is taken off between the cathode of the tube and ground. This type of amplifier is also called a cathode follower. Although we may call it an amplifier, it is impossible to have voltage amplification in a stage of this type. It does have some useful applications, primarily because it has a low output impedance and, therefore, can drive a low-impedance load.

The third type of amplifier is shown at C in Fig. 44-1. The signal to be amplified is applied between the cathode of the tube and ground. The output voltage is taken off between the plate of the tube and ground. If a bias resistor or supply is placed in the grid circuit, it is bypassed so the grid is at ground potential as far as signals are concerned. This circuit has gain, and the gain may exceed that of the grounded-cathode amplifier.

You will not ordinarily find an amplifier of this type in a radio receiver, but you may find it in the tuner of a television receiver.

In this experiment you will build the three types of amplifiers shown in Fig. 44-1, feed ac signals to their inputs, measure the signal voltage at their outputs and compare their gains.

Experimental Procedure: For this experiment, you will need the experimental chassis with the circuit board and wiring on it, your tvom and the following:

- 1 3.3K-ohm resistor
- 1 4.7K-ohm resistor
- 1 22K-ohm resistor
- 1 470K-ohm resistor
- 1 1-megohm resistor
- 1 .25-mfd capacitor
- 1 20-mfd, 150V electrolytic capacitor

Begin by constructing the grounded-cathode circuit shown in the schematic diagram in Fig. 44-2. The 1K-ohm potentiometer should still be mounted on the right front corner of the chassis with its terminals upward. The center terminal is terminal 2, the terminal nearest the front of the chassis is terminal 1, and the terminal toward the rear of the chassis is terminal 3.

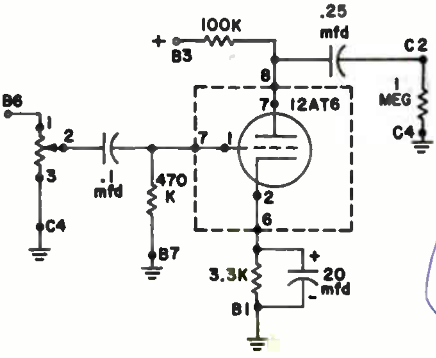


Fig. 44-2. The grounded-cathode amplifier circuit.

14V

Remove the jumper wire from terminal B1 to lug 6 and replace it with a 3.3K-ohm resistor.

Connect a 20-mfd electrolytic capacitor in parallel with the 3.3K-ohm resistor, with the polarity shown. Replace the 47K-ohm resistor between terminal B7 and lug 7 with a 470K-ohm resistor.

Complete the wiring using Fig. 44-2 and be sure to check all connections. You should now be ready to begin taking measurements.

Step 1: To determine the gain of a grounded-cathode amplifier.

Energize the circuit and let the tube warm up. Then adjust the input signal to the amplifier as follows. Set the tvom to measure ac voltage and connect the ground clip to the chassis. Adjust the 1K-ohm potentiometer for .2 volt ac at its center terminal. Switch your tvom to the low range for greater accuracy in adjusting the potentiometer. Move the tvom probe to circuit board lug 7 and notice that you have about the same voltage at the grid of the tube.

Set the tvom range switch to the 30-volt position and measure the ac signal in the plate circuit. Touch the probe to circuit board lug 8 and read the meter carefully. Record this value in the space for the output voltage in Fig. 44-3.

The .25-mfd capacitor and the 1-megohm resistor represent a fairly typical load on a voltage amplifier. Move the

.24).1800 .2)4.0₁ .2)14.0₁ 14 192168

STEP	GROUNDED ELEMENT	INPUT	OUTPUT	GAIN
1	CATHODE	.2V	14V	70
2	PLATE	.2V	4V	.7
3	GRID	.2	20V	100

Fig. 44-3. The chart for Experiment 44.

tvom probe to terminal C2 and measure the voltage across the 1-megohm resistor. As you can see, it is about the same as the voltage at the plate of the tube.

Next, compute the gain of the amplifier from the information in the chart. To do this, divide the input voltage of .2 volt into the output voltage you just measured. Record the gain for this circuit in the chart in Fig. 44-3.

Move the probe to lug 6. Note that there is no appreciable ac voltage at the tube cathode.

To show that a lower value of load resistor will reduce the output voltage, turn the circuit off, and replace the 1-megohm resistor with a 22K-ohm resistor. Energize the circuit and measure the plate signal again at lug 8 of the circuit board. Jot down the value in the margin of this page.

14V

Step 2: To measure the gain of a grounded-plate amplifier.

Turn the power off and unsolder the lead of the 20-mfd electrolytic capacitor from terminal 6 of the circuit board and push it out of the way. Unsolder the lead of the .25-mfd capacitor from lug 8 and move it to lug 6 of the circuit board. Also, unsolder and remove the 100K-ohm plate-load resistor. Connect a short length of hookup wire in its place between circuit board lug 8 and terminal B3. You should now have the circuit shown in the schematic in Fig. 44-4. This circuit is generally called a cathode follower or grounded-plate amplifier.

Energize the circuit and set the 1K-ohm potentiometer for .2 volt ac at the grid of the tube. Move the probe to the plate circuit, terminal 8 of the circuit board, and note the absence of an ac signal.

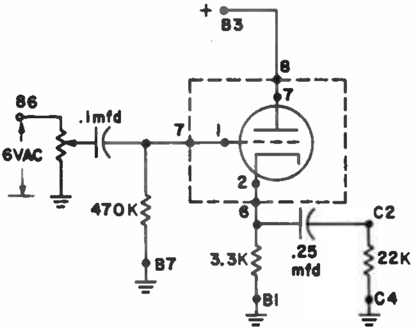


Fig. 44-4. The grounded-plate amplifier circuit.

The output signal appears in the cathode circuit. Touch the probe to circuit board lug 6 and measure the output voltage. Record your reading in the space provided in Fig. 44-3. Compute the "gain" by dividing the input signal of .2 volt into the output signal level. The gain should be somewhere between .5 and .1.

Replace the 22K-ohm resistor in the output circuit with a 4.7K-ohm resistor. Apply power to the circuit and note that the output voltage changes very little with the change in the load.

Step 3: To show gain in a grounded-grid circuit.

Turn the circuit off and wire the circuit shown in Fig. 44-5. Remove the

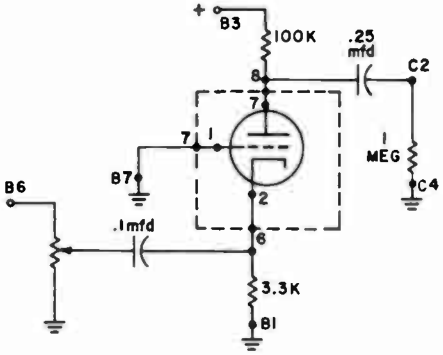


Fig. 44-5. The grounded-grid amplifier used in Step 3.

hookup wire between the plate terminal, lug 8, and terminal B3. Connect a 100K-ohm resistor in its place. Move the .1-mfd capacitor lead from lug 7 to lug 6 of the circuit board. Ground the grid by connecting a short length of hookup wire from lug 7 to terminal B7. Move the lead of the .25-mfd capacitor from lug 6 to lug 8. Replace the 4.7K-ohm resistor with a 1-megohm resistor.

Turn the circuit on and adjust for .2 volt ac at the tube cathode terminal, circuit board lug 6. If you cannot get .2 volt, set the potentiometer for maximum, then measure and record the voltage at the cathode in Fig. 44-3. Move the tvom probe to the center terminal of the potentiometer and measure the voltage there. Note that it is much higher than the voltage at the cathode.

2d Measure the output voltage at the plate terminal, lug 8 of the circuit board. Record the output voltage in Fig. 44-3, then compute the gain of the amplifier. Record the gain in the space provided in the chart.

Discussion: In this experiment you demonstrated amplifier circuits. You saw that when an ac signal is applied to a tube along with sufficient bias voltage, an input signal is produced. In all three circuits you used cathode bias. Cathode-to-plate current flowing from ground up through the 3.3K-ohm resistor made the cathode positive. Since the grid was returned to ground and remained at about ground potential, the grid-to-cathode voltage was negative.

From your chart in Fig. 44-3, you can see that the grounded cathode amplifier, which is a conventional amplifier circuit, has high voltage gain, with a gain of about 40. In carrying out Step 1, you should have found that there was little if any loss in the signal voltage across the .1-mfd input coupling capacitor. This is due to the fact that the grid circuit has a relatively high input impedance. Because no current flows, no signal power is dissipated in the grid circuit. The grid signal has only to vary the potential between the grid and cathode in order to control the tube plate current.

The grounded-cathode amplifier also has high output impedance. This means that the load resistance must be high if the tube is to have high amplification. As you demonstrated, connecting a low-resistance load caused a substantial reduction in the signal voltage at the plate.

The larger capacitor across the cathode resistance prevented the cathode bias voltage from varying with plate current. Therefore, the variations in plate current were proportional to the variations in grid voltage and high gain was realized.

The grounded-plate amplifier, which is called a cathode follower, has no voltage gain. A "gain" of .8 to .9 is typical of the circuit you used in Step 2. As you have already learned, a cathode follower is used primarily for matching a high impedance source to a low impedance load.

The input impedance is high as illustrated by the absence of signal voltage drop across the input coupling capacitor, and the output impedance is quite low.

The output impedance of a cathode follower is lower than the value of the cathode resistor. When you reduced the output load resistance to 4700 ohms, you should have observed very little reduction in the level of the signal at the cathode. This indicates that this load resistance is high compared to the amplifier output impedance.

In general, the characteristics of the grounded-grid amplifier are opposite to those of the cathode follower. The grounded-grid circuit, which you used in Step 3, has relatively high gain, low input impedance and high output impedance. Thus, it is useful for matching the impedance of a low impedance source to a high impedance load. In Step 3, you should have measured a gain of about 40.

Grounded-grid amplifiers are most often used to couple cathode followers to conventional amplifier stages. The fact that the grid is grounded makes the grid act as a shield between the cathode and plate. Consequently, it provides shielding between the amplifier input and output circuits and prevents signal energy from being coupled back through the tube.

The low impedance of the grounded-grid amplifier is largely due to the low value of resistance across which the input signal is developed. Voltage divider action results in most of the signal being dropped across the coupling capacitor between the signal source and the tube.

In this experiment, the word ground refers to signal ground. This may be dc ground, such as a connection to the chassis or B–. It may also be a point having a capacitor connected between it and B– (ground) such that no signal is developed at that point. Thus, in Step 2, the plate was at signal ground while having a potential of +80V applied.

From this experiment, we can make the following conclusions:

1. The conventional (grounded-cathode) amplifier has high gain, high input impedance and high output impedance;

2. The grounded-plate (cathode follower) amplifier has no gain, high input impedance and low output impedance; and

3. The grounded-grid amplifier has high gain, low input impedance and high output impedance.

Instructions for Statement No. 44: For this Statement, you will change the grid circuit of a grounded-grid amplifier and determine the effect of the gain. With the circuit turned off, unsolder and remove the length of hookup wire connecting circuit board lug 7 and terminal B7. Connect a 470K-ohm resistor and a 20-mfd electrolytic capacitor in parallel between these terminals, as shown in the schematic diagram in Fig. 44-6.

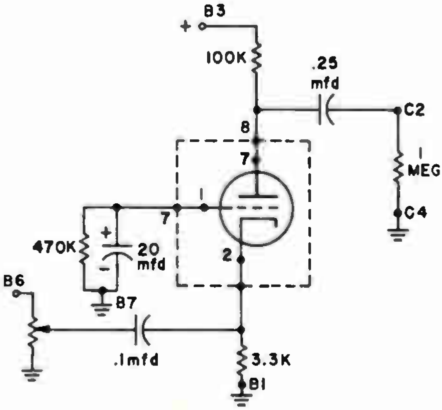


Fig. 44-6. The circuit for Statement 44.

Energize the circuit, measure the input and output signal voltages as before. Turn your equipment off and compute the gain.

Compare the gain with the gain for Step 3, which you recorded in the chart in Fig. 44-3. You are now ready to answer the Statement.

100
.2)20.0

Statement No. 44: When I installed the capacitor and resistor in the grid circuit of the grounded-grid amplifier circuit, I found that the gain of the stage:

[✓ *(1)*] *did not change appreciably.*
(2) increased considerably.
(3) decreased considerably.

Transistor Fundamentals

In the first four experiments you have seen how a tube works and how it amplifies the signal. In the next six experiments you will see how a transistor works, how it is biased, how it amplifies signals and the various ways in which signals are applied to and removed from transistor circuits.

In these experiments, you will use the low power NPN transistor. This transistor is just the opposite of the transistor used in the preceding kit. It is a silicon NPN transistor, made of a piece of silicon which has been doped with impurities which give the base a P characteristic and the emitter and collector N characteristics. The transistor cannot safely pass high currents. The base current should not exceed a few milliamperes and the collector current should be limited to about 20 ma. The transistor has high gain. This means that small changes in base-emitter current can produce relatively large changes in the collector current.

A transistor is normally operated with forward bias on the base-emitter junction and reverse bias on the base-collector junction. Because we will be using an NPN transistor, the base should be positive with respect to the emitter and the collector should be positive with respect to the base. Note that this makes the emitter the least positive (or most negative) element of the transistor.

PRELIMINARY CONSTRUCTION

First you will assemble the low voltage power supply. This supply will be constructed on the circuit board which you received in Kit 1T. You will need the following parts:

1 Circuit board (EC24)
2 LV silicon diodes
2 200-mfd, 35V electrolytic capacitors
1 100-ohm resistor
1 1K-ohm resistor
4 1/4″ X 4-40 screws
4 4-40 hex nuts

Mount circuit board EC24 on the left side of the chassis over the 500K-ohm potentiometer and the neon lamp. Secure the board with four 4-40 screws and nuts.

Fig. 7 shows the circuit board, EC24, with the complete power supply assembled and mounted on the chassis. Refer to this figure as you mount the parts.

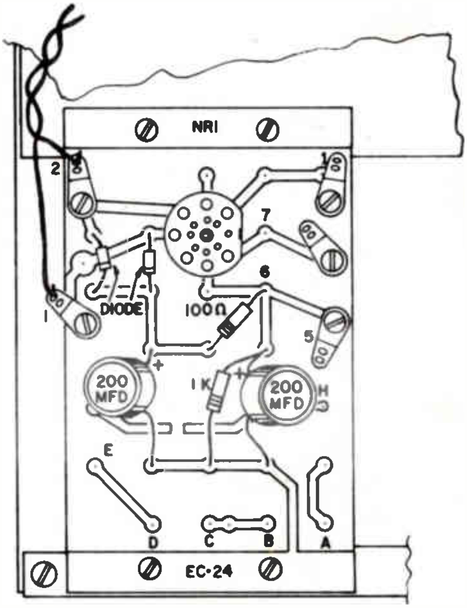


Fig. 7. Assembling the LV power supply.

You received the circuit board and the diodes in Kit 1T. In wiring EC24, push the parts down against the board and cut off the excess lead lengths.

Identify the anode and cathode leads of the two low voltage silicon diodes. Install each on the foil side of the board as shown, with the cathode lead toward hole D on the circuit board. Solder the leads.

Identify the leads of the two 200-mfd electrolytic capacitors and mount them as shown in the diagram. Note that the positive lead of each capacitor is toward the tube socket. Solder their leads to the foil.

Position the 100-ohm resistor as shown and install it on the board. Solder the leads.

Connect a 1K-ohm resistor to the foil as shown. Electrically, the resistor is between lug 5 and ground.

Check your work against the drawing very carefully.

Connect lengths of hookup wire between terminals B5 and B6 and terminal lugs 1 and 2 on the circuit board.

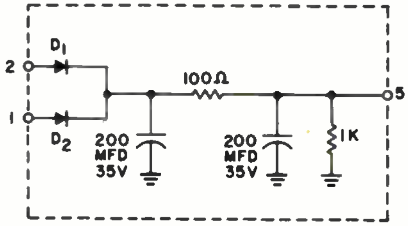


Fig. 8. Schematic diagram of the LV power supply on circuit board EC24.

Before you turn the circuit on, check the wiring against the schematic diagram in Fig. 8. Note that you have a full-wave rectifier operating off the center-tapped low voltage winding of the power transformer. The two 200-mfd capacitors and the 100-ohm resistor form a pi type filter network, producing filtered dc at lug 5 of the circuit board.

To test your low voltage power supply wiring, apply power to your chassis and measure the dc voltage between circuit board lug 5 and the chassis. You should read approximately 8 volts dc. Turn the power off.

Next, you will install an NPN transistor (TS21) on circuit board EC25. The transistor should not be subjected to physical strain or excessive heat on the leads. Therefore you should use the following procedure to install it: Identify the leads and bend them to fit the connections; grasp each lead with your longnose pliers and hold it in the molten solder. The pliers will serve as a heat sink and carry away the excess heat.

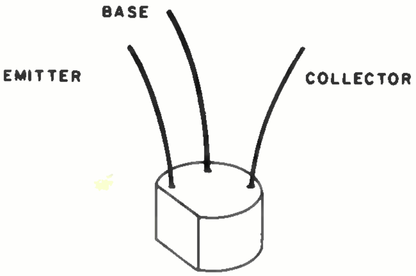


Fig. 9. Identifying the leads of the 2N5134 transistor.

Refer to Fig. 9 to identify the transistor leads. This is a bottom view. Note that there is a flat spot on the transistor case next to the emitter lead. Fig. 10 shows how to position the leads. Bend

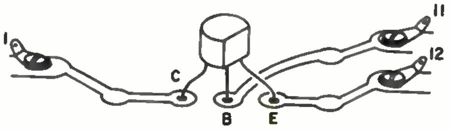


Fig. 10. Mounting the transistor on the experimental circuit board.

the leads and install the transistor as shown.

Unsolder and disconnect the filament leads to lugs 4 and 5 of EC25. Also unsolder and remove the lead between terminals A6 and B3. Unsolder and remove the parts connected to lugs 6, 7, and 8, terminals C2 and C4 and the 1K-ohm potentiometer.

EXPERIMENT 45

Purpose: To show the need for bias current in transistors; to show that a transistor can provide amplification and to show that the collector load resistance will affect the gain of a transistor amplifier.

Introductory Discussion: In an earlier experiment, you found that the current flowing in the collector circuit of a transistor can be controlled by placing a potential across the base-emitter junction. Now you will demonstrate the operation of a practical amplifier circuit and plot the relationship between base current and collector current.

In parts of this experiment, you will have to determine and compare currents. You will use the indirect method which you have used before to determine the current in these circuits: measure the voltage drop across a series resistor and divide the voltage by the resistance value. To simplify these computations, remember that in a 1,000-ohm resistor, the current in ma is equal to the voltage across the resistor in volts.

That is, if you measured 3.6 volts across a 1,000-ohm resistor, the current would be 3.6 ma. In measuring the current in a 10,000-ohm resistor, the current in microamperes is equal to the voltage across the resistor multiplied by 100. For example, if you measured 0.36 volts across a 10,000-ohm resistor, the current would be 36 microamperes.

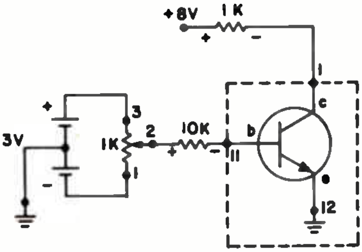


Fig. 45-1. The circuit for Step 1 and Step 2.

Experimental Procedure: In order to perform this experiment, you will need the experimental chassis with two circuit boards mounted, the tvom, and the following parts:

1	1,000-ohm resistor
1	4,700-ohm resistor
1	10K-ohm resistor
2	Flashlight cells

You should already have a 1K-ohm potentiometer and two circuit boards mounted on the experimental chassis. The low voltage power supply is wired on circuit board EC24 and the NPN transistor is mounted on circuit board EC25.

Construct the circuit shown in the schematic in Fig. 45-1 and in the diagram in Fig. 45-2. The dashed line in the schematic of Fig. 45-1 encloses the wiring

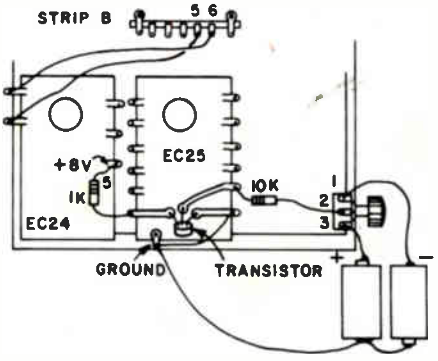


Fig. 45-2. Wiring layout for Step 1.

on circuit board EC25. When you complete your wiring, you will be ready to proceed with the experiment.

Step 1: To show that the base-emitter junction of a transistor must be forward biased for the transistor to operate and pass collector current.

Connect the tvom to measure the voltage between the chassis and the center terminal of the 1K-ohm potentiometer on the right side of the chassis. Set the potentiometer for −1 volt at terminal 2. Move the tvom leads to measure the voltage dropped across the 1K-ohm collector load resistor connected between lug 1 on circuit board EC25 and the +8V dc supply at lug 5 of EC24. With the tvom polarity switch set to "normal," connect the ground clip to lug 1 of EC25 and the probe to lug 5 of EC24.

Turn the circuit on and measure the voltage across the 1K-ohm resistor. Compute the current in the collector circuit. Record the current on the first line in the collector-current column in Fig. 45-3. The value should be close to zero.

BASE VOLTAGE	COLLECTOR CURRENT
−1 −.6	0
0	0
+ 1 +.6	1 mA.

Fig. 45-3. The chart for use with Step 1.

Using the same procedure, set the potentiometer for zero volts at terminal 2 of the 1K-ohm potentiometer and measure the corresponding collector current. Record the value in the chart in Fig. 45-3. Repeat the measurement with the potentiometer set to provide +1 volt at terminal 2. Record your results and turn off the power.

Step 2: To show that a transistor can amplify signal current.

Connect the tvom across the 10,000-ohm resistor which is connected in series with the base of the transistor. Observe the polarity of the voltage shown in Fig. 45-1 and connect your tvom leads accordingly. With the circuit turned on, adjust the 1K-ohm potentiometer for a voltage of .3 volt across the resistor. This reading corresponds to a base current (I_b) of .030 ma or 30 μa.

Without changing the adjustment of the 1K-ohm potentiometer move the tvom leads to the 1K-ohm collector load resistor and measure the collector current. Record this current in the collector current column of Fig. 45-4. Next, measure the collector voltage between the collector and the chassis and record it in Fig. 45-4.

Following the same procedure, set the base current to 20 microamperes (0.2 volt) and measure and record the collector current and the collector voltage. Finally adjust the base current to 40

BASE CURRENT	COLLECTOR CURRENT	COLLECTOR VOLTAGE
.03 ma	.8 MA	6.8V
.02 ma	.34 mA	7.4V
.04 ma	1.16 MA	6.4V

Fig. 45-4. The chart for Step 2.

microamperes (0.4 volt) and record the collector current and voltage measurements.

Step 3: To show that the collector load resistance affects the voltage gain.

Turn your circuit off and replace the 1,000-ohm collector load resistance with a 4700-ohm resistor. Fig. 45-5 shows a schematic diagram of this circuit.

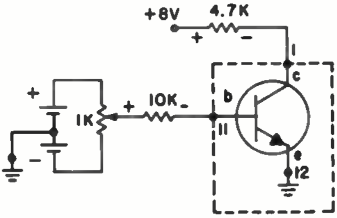


Fig. 45-5. The circuit used for Step 3.

Turn the circuit on and adjust the 1K-ohm potentiometer for a base current of 30 microamperes (0.3 volt across the 10,000-ohm resistor). Next measure the voltage between the collector terminal, lug 1, and ground. Record your reading in Fig. 45-6. Repeat the measurements using base currents of 20 microamperes and 40 microamperes and record the base current and collector voltage readings in Fig. 45-6. When you finish these measurements, turn the circuit off.

BASE CURRENT	COLLECTOR VOLTAGE
.03 ma	4.4V
.02 ma	6.2V
.04 ma	3.6V

Fig. 45-6. The chart for Step 3.

Discussion: In Step 1, you measured the collector current with different voltages applied to the base circuit. The base-emitter current is commonly called base current. You should have read close to zero collector current with both −1 volt and 0 volt applied to the base circuit.

Forward base current is required for conduction in a transistor. This is an NPN transistor, so when the base-emitter junction was reverse biased or when no voltage was applied, you had only "leakage" current through the emitter-collector path. Conduction took place when you forward biased the base-emitter junction by applying a positive voltage.

Assuming that we wanted to amplify a signal which varies in both the positive and negative directions, we needed a forward bias current so the negative portion of the signal would not reverse bias the transistor.

In Step 2 you measured the collector current with three values of base current. If you assume from the information in the chart in Fig. 45-4 that the bias current is 30 microamperes, you should see that the collector current variations are almost proportional to the changes in base current. If we use 30 microamperes of base current as a reference, we find an increase or decrease of 10 microamperes of base current causes about a .5 ma variation in collector current.

For linear amplification, a base bias current is needed. The signal causes the base current to vary above and below the bias level. This bias must be high enough so that, as the signal varies, the base current never reaches the cutoff level, which is near zero, because this would distort the amplified signal.

The only thing you changed in the circuit for Step 3 was the collector load

$\frac{.1V}{10K\Omega}$ ₮ $10k\overline{).10000}$ .01 m

resistance. By comparing the collector voltage readings for Steps 2 and 3 in the charts in Figs. 45-4 and 45-6, you can see that the variations in collector voltage are much greater with the higher value collector load resistor. This means that the voltage amplification is greater since the input signal variations were unchanged.

Notice the phase relationship between input and output voltages in this circuit. An increase in base voltage causes an increase in base current. This increases the collector current, producing a greater voltage drop across the collector load resistor. When we measure the collector voltage with respect to ground, we find that the voltage has decreased. The phase of the signal is reversed between input and output, just as it is in the conventional vacuum-tube amplifier circuit.

Instructions for Statement No. 45: For this Statement you will determine the amount of base current at which the transistor reaches saturation. (Saturation occurs when an increase in the input current produces no appreciable change in the output.) Connect your tvom to measure the voltage between the collector and ground, and turn the power on. Increase the base voltage until the collector reaches its minimum or saturation value. Then measure the voltage across the 10,000-ohm base resistor and determine the base current. Answer the Statement, turn the circuit off, and disconnect the 3-volt battery.

Statement No. 45: As I increased the base current, I found that the transistor became saturated with a base current of:

[✓ *(1)*] *less than 1 ma.*
(2) approximately 3 ma.
(3) between 6 and 10 ma.

EXPERIMENT 46

Purpose: To compare the characteristics of the common base, common emitter, and common collector transistor amplifier circuits.

Introductory Discussion: The three configurations for a transistor amplifier are common emitter, common base, and common collector. In many ways, they are similar to the three vacuum tube amplifier configurations which you have already seen. You have already worked with the common emitter transistor amplifier.

In each transistor amplifier configuration, as shown in Fig. 46-1, the input and output signals share one common element. In the common base circuit, the input is applied between the emitter and base and the output is taken between the collector and the base. In the common

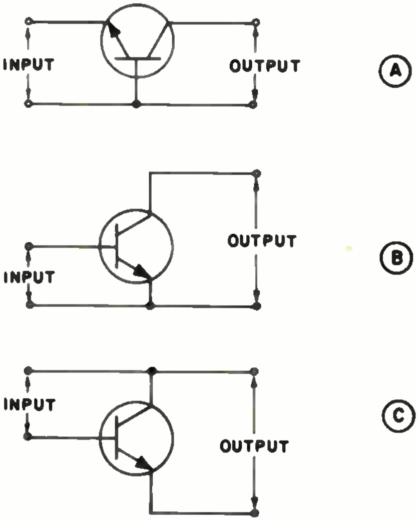


Fig. 46-1. The signal input and output terminals for the (A) common base, (B) common emitter and (C) common collector transistor amplifier configurations.

emitter circuit, the input is applied between the base and emitter and the output is taken between the collector and emitter. In the common collector circuit, the input is applied between the base and collector and the output is taken between the emitter and collector.

The connections shown in Fig. 46-1 refer to the ac signal connections. Due to the forward and reverse bias requirements, the common element may be at some dc level other than ground. However, the common element is held at signal ground by a bypass capacitor or by the low impedance of the dc source.

In this experiment, you will apply ac signals to the amplifier configurations and measure the voltage and current gain of each to compare the circuit characteristics.

Experimental Procedure: In order to carry out this experiment you will need the experimental chassis, your tvom, and the following parts:

1 10-ohm resistor
2 1K-ohm resistors
1 4.7K-ohm resistor
2 10K-ohm resistors
1 47K-ohm resistor
2 100K-ohm resistors
1 100-mfd electrolytic capacitor
1 Alligator clip

You will begin by constructing the circuit shown in the schematic diagram in Fig. 46-2. This is an adjustable voltage divider for supplying the proper level of ac signal voltage to the amplifier and the common base amplifier circuit which you will use for Step 1. The adjustable voltage divider will be used in all of the steps.

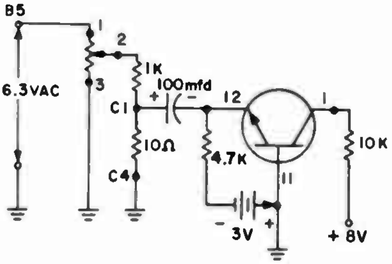


Fig. 46-2. The voltage divider and common base amplifier circuit you use for Step 1.

Loosen the screw at hole U and turn terminal strip C around so that terminal C1 is toward the front of the chassis. Retighten the screw. This will make the wiring easier.

Construct the voltage divider portion of the circuit first. Connect and solder lengths of hookup wire between terminal B5 and terminal 1 of the 1K-ohm potentiometer and between terminal C4 and terminal 3 of the potentiometer. Connect a 1K-ohm resistor from terminal 2 of the potentiometer to terminal C1. Connect a 10-ohm resistor between terminals C1 and C4. Solder the positive lead of a 100-mfd capacitor to terminal C1. Solder the negative lead of the capacitor to lug 12 of circuit board EC25.

Next, wire the amplifier. Move the short ground wire from lug 12 to lug 11 on EC25. Solder a 10K-ohm resistor between lug 1 of EC25 and lug 5 of EC24. Solder a 4.7K-ohm resistor to lug 12 of EC25. Leave the other lead free.

You should still have two flashlight cells connected in series, forming a 3-volt battery. Solder a test clip to the positive battery lead. This will simplify your work a little later. Solder the negative battery lead to the free lead of the 4.7K-ohm resistor soldered to lug 12.

Check your wiring against the schematic and be sure all connections are soldered. To complete the 3-volt battery circuit, you will clip the positive battery lead to the chassis.

Step 1: To show that the common base amplifier has voltage gain.

Energize the circuit, connect the clip from the 3-volt battery to the chassis, and set your tvom to measure ac voltage. Measure the voltage between terminal 2 (the center terminal) of the 1K-ohm potentiometer and the chassis. Adjust the potentiometer for a reading of 2.5 volts. Use the 3-volt range. The 1K-ohm resistor and 10-ohm resistor connected between potentiometer terminal 2 and ground form a 100:1 voltage divider. With the potentiometer set for 2.5 volts, about .025 volts is being applied to the transistor amplifier circuit at terminal C1.

After you have adjusted the input voltage, measure the ac output voltage between ground and the collector of the transistor. Record this value as the output voltage for Step 1 on the first line of the chart in Fig. 46-3. Note that the input voltage has been written in.

Now that you have both the input and output voltage levels, compute the amplifier voltage gain using the formula:

$$V_G = \frac{V_{out}}{V_{in}}$$

STEP	INPUT	OUTPUT	GAIN
1	.025V	2[illegible] V	≃ 100
2	.285h	.25 ma	≃ <1

Fig. 46-3. Record your results for Steps 1 and 2 here.

and record the gain for Step 1 in the chart.

Turn the circuit off. Be sure to disconnect the battery clip.

Step 2: To show that the common base amplifier has a current gain of less than 1.

Modify your circuit as shown in Fig. 46-4. Solder a 10K-ohm resistor to terminal 2 of the potentiometer. Unsolder the capacitor lead from terminal C1 and solder it to the free lead of the 10K-ohm resistor.

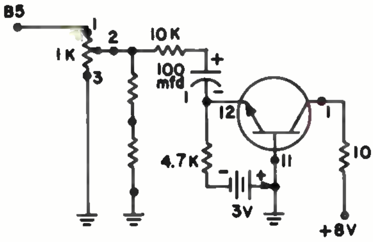


Fig. 46-4. The circuit for Step 2.

To determine the current gain, you will use the following procedure: First set the potentiometer for a given amplifier output voltage. This will give you the output signal current through the load resistor. Then measure the signal voltage drop across a resistor in series with the amplifier input. Use this value to compute the input signal current. Finally, divide the output current by the input current to find the current gain.

Now you can proceed with this step. Energize the circuit and connect the 3-volt battery clip. Set the 1K-ohm potentiometer for an output of 2.5 volts between the collector, lug 1, and ground. This corresponds to the output current of .25 ma, as recorded in the chart in Fig. 46-3.

Measure the ac voltage between ground and the resistor lead connected to the potentiometer. Jot down the value for reference. Now measure the signal voltage between ground and the resistor lead connected to the coupling capacitor. The difference between these two readings is the signal voltage across the 10K-ohm series resistor.

2,85

0V

.285

10K) 2.85

Now that you know the voltage across the resistor, you can find the input signal current. Divide the voltage reading by 10,000. You can do this simply if you remember that the current through the resistor in ma is 1/10 the voltage across the resistor in volts. Record the input current in the space provided in the chart in Fig. 46-3.

Compute the current gain of the amplifier. Use the formula:

$$I_G = \frac{I_{out}}{I_{in}}$$

Your answer should be some number between .7 and 1. Record the value in the chart in Fig. 46-3 and turn the circuit off.

Step 3: To show that the common emitter amplifier has voltage gain.

Construct the circuit shown in Fig. 46-5. Unsolder and disconnect the leads from lug 12 of the circuit board. Unsolder the ground wire from lug 11. Solder the free end of this wire to lug 12.

Unsolder and remove the 4.7K-ohm resistor. Solder the negative lead of the 3-volt battery to a convenient ground point. Solder one lead of a 47K-ohm resistor and the positive lead of the 100-mfd capacitor to lug 11. Solder the negative capacitor lead to terminal C1. Check your wiring and be sure all connections are soldered.

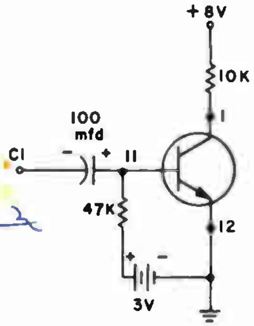


Fig. 46-5. The common emitter amplifier circuit for Step 3.

To produce an input of .025V ac between the base and emitter of the transistor, energize the circuit, clip the positive battery lead to the 47K-ohm resistor and set the potentiometer for 2.5V ac across the voltage divider.

Move the tvom probe to lug 1 and measure the output signal between the collector of the transistor and ground. Record the output voltage in the space provided in Fig. 46-6. Compute the voltage gain of the circuit by dividing the output voltage you just recorded by the input voltage of .025V. Record the voltage gain in the chart.

Turn your circuit off.

Step 4: To show that the common emitter amplifier has current gain.

Connect two 100K-ohm resistors in parallel. Solder one end of this parallel

STEP	INPUT	OUTPUT	GAIN
3	.025V	~~[illegible]~~ 2.5	150
4	.06	.25 ma	4

Fig. 46-6. Record your results for Steps 3 and 4 here.

4.

.06) 2.5

24

16
15.8) 250μ
15
100

4
15.8
120
103

combination to terminal 2 of the potentiometer. Unsolder the capacitor lead from terminal C1 and solder it to the free leads of the two 100K-ohm resistors.

Turn your circuit on and adjust the potentiometer for an output of 2.5 volts between ground and the collector of the transistor at lug 1. This corresponds to a collector output signal current of .25 ma, as shown in the chart in Fig. 46-6. Without readjusting the potentiometer, determine the input current. Measure the ac voltage across the 50K-ohm input series resistance formed by the two parallel-connected 100K-ohm resistors. Use the technique described earlier: measure the voltage between ground and each end of the resistance and take the difference. Divide this difference voltage by 50 to find the input signal current in ma. Record the current value in the space provided in Fig. 46-6.

3V

To find the current gain, divide the output signal current by the input current recorded in Fig. 46-6. Record the current gain in the space provided in the chart.

Turn the circuit off and disconnect the battery clip.

Step 5: To show that the common collector amplifier has a voltage gain of less than 1.

.06μ
50K) 3.00
300

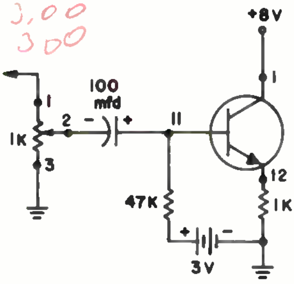


Fig. 46-7. The common collector circuit for use in Step 5.

Construct the circuit shown in the schematic diagram in Fig. 46-7. Remove the length of hookup wire connected between lug 12 and ground and replace it with a 1K-ohm resistor. Unsolder and remove the 10K-ohm resistor connected to lug 1. Solder a length of hookup wire between lug 1 of EC25 and lug 5 of EC24. Unsolder and remove the two 100K-ohm resistors from the circuit. Unsolder the capacitor lead from the 50K-ohm resistance and solder it to terminal 2 of the potentiometer.

Turn the circuit on and adjust the 1K-ohm potentiometer for .25V ac between the base of the transistor (lug 11) and ground. Move the probe of the tvom to lug 12 and measure the ac output voltage across the 1K-ohm emitter load resistor. Record this value for the output voltage in Fig. 46-8. We have already indicated the input voltage of .25V.

.25

STEP	INPUT	OUTPUT	GAIN
5	.25V	.25	1
6	15.8μ	250 μa.	16

Fig. 46-8. Record your results for Steps 5 and 6 here.

Compute the voltage "gain" by dividing the output voltage by the input voltage of .25V. The result should be between .9 and 1. Record the gain in the space provided in the chart in Fig. 46-8.

Turn the circuit off and disconnect the battery clip.

Step 6: To show that the common collector amplifier has current gain.

Unsolder the capacitor lead from terminal 2 of the 1K-ohm potentiometer.

1.80
-.25
1.55

.0155
100K) 1.55

Separate the leads of the 100K-ohm resistors and connect the capacitor in series with one of the 100K-ohm resistors.

Turn the circuit on, connect the battery, and adjust the potentiometer for an output of .25V ac across the 1K-ohm emitter load resistor. This corresponds to an output signal current of .25 ma or 250 μa. Now determine the input current flowing into the base circuit. Measure the ac voltage across the 100K-ohm series resistor using the technique outlined in Steps 2 and 4. Divide the voltage across the resistor by 100,000 to find the input current. The current in μa is equal to 10 times the voltage across the resistor in volts. For example, a voltage of .8V corresponds to 8 μa. Record the input current in the chart in Fig. 46-8.

15.5 μa

Compute the current gain by dividing the output signal current by the input signal current as you have done previously. Record the current gain in the chart in Fig. 46-8.

Turn the equipment off.

Discussion: In this experiment, you demonstrated the voltage and current gain characteristics of the three basic transistor amplifier configurations. In all three, the base, emitter and collector currents are fixed largely by the characteristics of the transistor: a small current flowing across the forward biased base-emitter junction causes a much larger current to flow from the emitter across the base to the reverse biased base-collector junction. The levels of the input and output currents are primarily due to whether they are the emitter, base or collector current or a combination.

The voltage gain of any amplifier configuration is generally determined by the current gain of the transistor and the input and output resistances.

The important facts of this experiment are summarized in Fig. 46-3, Fig. 46-6, and Fig. 46-8. You can see that the common base amplifier has the highest voltage gain but the lowest current "gain." A voltage gain of 100 and a current gain of .8 are typical. The common collector stage has the lowest voltage gain and the highest current gain. Typical values are a voltage gain of .95 and a current gain of 30. The common emitter amplifier has medium voltage and current gains. Typical values are a voltage gain of 90 and a current gain of 4.

From basic transistor theory, you know that the emitter current is the sum of the base and collector currents. You also know that the collector current is many times the value of the base current. You know that normally the base-emitter junction is forward biased and that it acts like a forward biased diode and has a low resistance. Conversely, the base-collector junction is reverse biased and hence has a much higher resistance.

With this information you can see that each amplifier configuration has different input and output impedances. The common base circuit has low input impedance and high output impedance. The input signal is applied to the emitter-base junction and the emitter current flows in the input signal circuit. On the other hand, the output impedance is roughly equal to the load resistance.

The common emitter circuit used in Steps 3 and 4 has moderate input impedance and high output impedance. The input is applied to the base-emitter junction, but only the base current flows in the input signal circuit. The output, taken across the emitter-base and base-collector junctions connected in series, is nearly equal to the resistance of the load resistor.

The common collector circuit, which you used for the last two steps, has very high input impedance. The input signal is applied across the base-collector junction, which is reverse biased and acts somewhat like an open circuit. Even with an input voltage of .25V, the input current was probably less than 10 μa (.01 ma).

From the work in this experiment you can see that the choice of an amplifier configuration must be based on the voltage and current gain requirements and input and output impedances. You will learn more about these configurations in your regular lessons.

One of the characteristics of the common base amplifier is that it does not reverse the phase of the applied signal: a positive-going change in the input signal produces a positive-going change in the output. For this Report Statement, you will determine whether or not the other amplifier configurations reverse the phase of the signal.

Instructions for Statement No. 46: Unsolder and remove the 100-mfd capacitor and the 100K-ohm resistor from the circuit and lay them aside. Solder a 100K-ohm resistor to lug 5 of EC24 and position the resistor so you can touch the other lead to lug 11 of EC25. You should now have the common collector circuit shown in Fig. 46-7, but without the ac input circuit.

Turn your circuit on, connect the battery clip, and measure the dc voltage
1.65 across the 1K-ohm output load resistor.
Touch the 100K-ohm resistor lead to the
+ transistor base to represent a positive dc signal voltage and note the direction of the change in dc output voltage. (The direction of the change depends on whether the emitter voltage increases or decreases when a positive signal is applied to the base.)

When you have made this measurement, turn the circuit off and change the amplifier to a common emitter configuration. Replace the 1K-ohm resistor with a length of wire and replace the wire connected between lug 1 and lug 5 of EC24 with a 10K-ohm resistor. The circuit will then be similar to the circuit shown in Fig. 46-5.

Connect the 3-volt battery, energize the circuit and measure the output voltage between the collector at lug 1 and ground. Touch the lead of the 100K-ohm resistor to the transistor base circuit and note the direction in which the collector voltage changes. You now have enough data to answer the Report Statement. Turn your equipment off.

Statement No. 46: **When I applied a positive input voltage to the common collector amplifier, I found that the amplifier**

(1) reversed
[✓ *(2) did not reverse*]

the phase of the signal and when I applied a positive input voltage to the common emitter amplifier, I found that the amplifier

[✓ *(1) reversed*]
(2) did not reverse

the phase of the signal.

EXPERIMENT 47

Purpose: To demonstrate and compare several methods of biasing a transistor using a single source of dc voltage.

Introductory Discussion: You already know that transistors are normally operated with forward bias on the base-emitter junction and reverse bias on the base-collector junction. Now you will see how both of these bias requirements can be obtained from a single source of dc voltage.

A simple bias arrangement using one dc source is shown in Fig. 47-1. A relatively high positive voltage is applied to the collector through a load resistor. This is an NPN transistor, so the collector voltage is positive with respect to the emitter. The base resistor is connected between the base and the collector supply voltage, thereby making the base positive. This causes a current to flow from the emitter across the base-emitter junction and through the base resistor to the positive source. Most of the voltage is dropped across the resistor, making the base slightly positive with respect to the emitter, and the collector highly positive with respect to the base. The bias requirements, therefore, are satisfied.

The base bias current in the circuit in Fig. 47-1 is totally dependent on the value of the bias resistor and the resistance of the base-emitter junction of the transistor. Any change in either will shift the transistor from the desired point on its characteristic curve. This may cause distortion in the output signal (if it is used as an amplifier) or damage to the transistor due to excessive current.

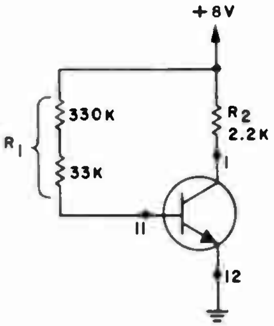


Fig. 47-1. The circuit for Step 1.

The basic bias circuit can be modified to make it more stable. By stable, we mean the transistor can be made to operate satisfactorily despite normal variations in resistor values, transistor characteristics, ambient temperature, etc. You will demonstrate this by reducing the value of a resistor and observing the effect on the output voltage.

Experimental Procedure: For this experiment, you will need the chassis, your tvom and the following parts:

- **1 1K-ohm resistor**
- **2 2.2K-ohm resistors**
- **1 4.7K-ohm resistor**
- **1 22K-ohm resistor**
- **1 33K-ohm resistor**
- **1 47K-ohm resistor**
- **1 220K-ohm resistor**
- **1 330K-ohm resistor**
- **1 10-mfd capacitor**
- **1 100-mfd capacitor**

Begin by constructing the circuit shown in Fig. 47-1. Unsolder and remove all parts and hookup wires from lugs 1, 11 and 12 of circuit board EC25. Do not remove the ac voltage divider wired on terminal strip C and the 1K-ohm potentiometer.

Connect a 2.2K-ohm resistor from lug 1 of EC25 to lug 5 of EC24. Connect together a 330K-ohm resistor and a 33K-ohm resistor and solder this resistor combination between lug 5 of EC24 and lug 11 of EC25. Connect a length of hookup wire between lug 12 of EC25 and any convenient ground point. Check over your work and solder all connections.

Your circuit is a common emitter amplifier stage having base bias supplied by a dropping resistor, R_1, of approximately 360K-ohms. Changes in collector current will be reflected in a variation in the voltage drop across the collector load resistor, R_2.

7.40 **Step 1: To demonstrate simple bias.**

.64
.76

Set your tvom to measure positive dc voltage on the 12V range and energize your circuit. Measure the voltage between ground and the collector of the transistor at lug 1. Record the reading in the space for V_C on the top line of the chart in Fig. 47-2. This is the output voltage. Note that the voltage you just measured is also the voltage across the transistor (between the collector and emitter). Then record the same reading for V_{CE} in the chart.

17.8
uA

Determine the base current by the indirect method. Measure the dc voltage across the base resistance, R_1, and divide the voltage reading by 360K. Jot down the base current in the margin. The current should be about 20 μa (.02 ma).

Measure the bias voltage between the emitter and the base. About .6V is typical. Record this value in the margin also.

52

To check for stability, short out the 33K-ohm resistor with a piece of wire or a screwdriver and measure the collector voltage again. The voltage should be noticeably lower. Record the new value for V_C and V_{CE} on the second line in the chart.

Now that you have the output voltages for base bias resistances of 360K and 330K-ohms, you can determine the change in collector voltage, ΔV_C. This is equal to the difference in the V_C readings. Record the change in the space provided in the last column. Turn the circuit off.

STEP	R_1	V_C	V_{CE}	ΔVC
1	360K	6.3	6.9	.1
	330K	5.2	5.2	
2	240K	5.7	4.9	.1
	220K	5.6	4.7	
3	52K	4.2	2.8	.3
	47K	4.0	2.4	
4	24K	4.40	2.9	.05
	22K	4.85	2.8	

Fig. 47-2. Chart for this experiment.

Step 2: To demonstrate simple bias with emitter stabilization.

Modify your circuit to that shown in Fig. 47-3. Replace the series-connected base resistors with a 220K-ohm resistor and a 22K-ohm resistor connected in series. Also, replace the ground wire in the emitter circuit with a 1K-ohm resistor.

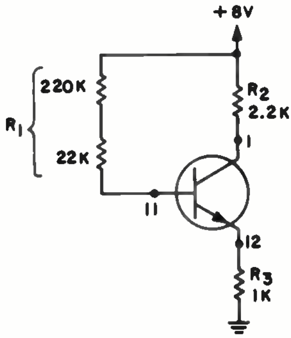


Fig. 47-3. The circuit used in Step 2.

Energize the circuit and measure the collector voltage, V_C. It should be close to the value you measured in Step 1. Record this voltage on the third line of the chart in Fig. 47-2. Move the ground clip of your tvom to lug 12 and measure the voltage across the transistor, V_{CE}. Record this voltage in the chart also.

Next, measure the voltage across the .81 emitter resistor, R_3. The voltage drop across this resistor is equal to the difference between the collector voltage and the collector-emitter voltage.

Test the circuit for stability. Short out the 22K-ohm resistor and measure the collector and collector emitter voltages again. Record your readings on the fourth line of the chart. Determine the change in the output voltage and record it in the last column.

Connect your tvom across the emitter resistor again and open and close the short across the 22K-ohm resistor. Note that when you short the resistor, the emitter voltage increases, thus counteracting the change in base current. Turn the circuit off.

137.

139 µ

Step 3: To show a bias method which uses base stabilization.

50K) 7.00

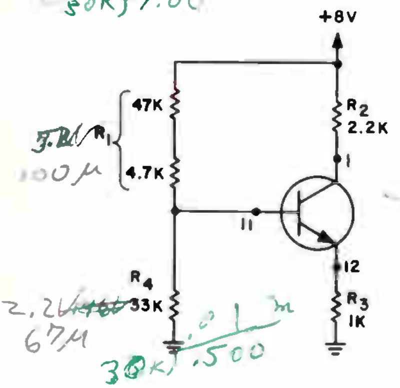


Fig. 47-4. The circuit for Step 3.

100 µ
67
33 µ

Wire the circuit shown in Fig. 47-4. Connect a 47K-ohm resistor and a 4.7K-ohm resistor in place of the base bias resistors used in the last step. Also, connect a 33K-ohm resistor between lug 11 and a ground point. Check your wiring against the schematic.

Energize the circuit and measure and record the collector and collector emitter voltages on the fifth line of the chart in Fig. 47-2. Check for stability by shorting out the 4.7K-ohm resistor and taking these voltage readings again. Record the values and determine the change in collector voltage. Record this value also.

Now, find the base current in the circuit. Note that part of the current through R_1 flows through R_4. Therefore, the base current is the difference between the R_1 and R_4 currents. First measure the voltage across R_1 and divide the voltage reading by the resistance value. Use 52K for the resistance of R_1 to make the computations easier. Next, measure the voltage across R_4 and find the current I_{R_4}. When you have found the currents, use the formula:

$$I_b = I_{R_1} - I_{R_4} = 33\mu$$

137.0 µ
13.9 µ
123.1 µ = I_b

The value should be in the vicinity of 20 µa. Turn the circuit off.

Step 4: To show a bias network using voltage feedback.

Unsolder and remove the 47K and 4.7K-ohm resistors. Connect a 2.2K-ohm resistor and a 22K-ohm resistor in series between lug 1 and lug 11 of the circuit board. The wiring of the circuit in Fig. 47-5 should now be complete.

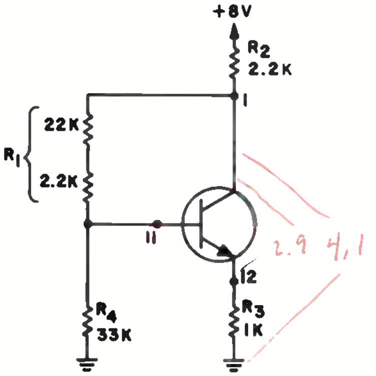


Fig. 47-5. The circuit used in Step 4.

Turn the circuit on and measure and record the voltages for V_C and V_{CE} with a bias resistance of 24K-ohms. Record your results in Fig. 47-2. Short out the 2.2K-ohm resistor and repeat the test to demonstrate the stability of this circuit. Record the change in collector voltage, ΔV_C, for this step. The change may be too small to observe on your meter. If it is, mark a dash in Fig. 47-2 for ΔV_C.

Turn the equipment off.

Discussion: You have demonstrated the four principal transistor biasing arrangements. In all four, forward bias for the base-emitter junction was obtained from the collector supply voltage. This eliminates the need for a second power source.

In Step 1, you used simple bias, which has the poorest stability. As you saw, the change in collector voltage was proportional to the change in the base resistor value. The change in the resistor value increased the base current and collector current by about 10 per cent.

In Step 2, emitter stabilization was used. Emitter current produced a voltage drop across the emitter resistor. This is reverse bias voltage for the base-emitter junction which opposes the forward bias and tends to decrease the base and collector currents. Thus, the base-emitter bias voltage was equal to the voltage directly across the terminals rather than between ground and the base. The stability of this circuit is better than the circuit shown in Fig. 47-1, as you found out.

The circuit in Step 3 combined emitter stabilization and base stabilization. As such, it was more stable than the preceding circuits. In addition to the emitter stabilization, the change in the base bias resistor value was offset by the bleeder resistor action of resistor R_4 in Fig. 47-4. Since part of the current through the forward bias resistor flowed through the bleeder resistor, the bias voltage at the base varied very little when the resistor value was decreased.

When you computed the bias current, you should have found a current of about 100 μa through R_1 and about 80 μa through R_4. Thus, the base current was approximately 20 μa.

The circuit used in Step 4 has the best stability. It uses the stabilization methods discussed earlier plus voltage feedback. Because the base bias network is supplied from the collector voltage, any change in collector voltage is reflected in a corresponding change in base voltage. Due to the 180° phase shift between the input and output, this minimizes the effect of the initial change, which was a reduction in the forward bias resistor value. You should have found that the collector emitter voltage varied by less than .1V.

Instructions for Statement No. 47: For this Report Statement, you will compare the amplification and collector voltages of the circuit in Fig. 47-5 with and without a bypass capacitor across the emitter resistor.

Use the ac voltage divider from Experiment 46 as a signal source. Connect a 100-mfd electrolytic capacitor between terminal C1 and lug 11 of the circuit board with the positive lead to lug 11 to form the circuit of Fig. 47-6. Energize the circuit and adjust the 1K-ohm potentiometer for 3V ac across the 100:1 voltage divider made up of the 1K-ohm and 10-ohm resistors. This voltage reading corresponds to an input signal of .03V ac.

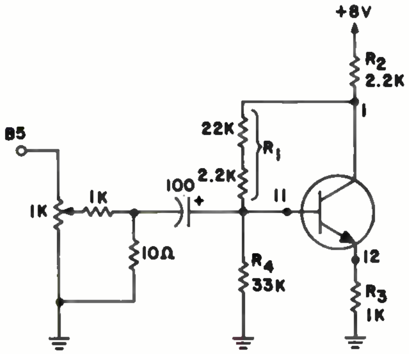


Fig. 47-6. The circuit used for the Report Statement.

Measure the ac voltage between the collector and ground. Also measure the dc collector voltage. Jot down the readings in the margin. Now, connect a 10-mfd capacitor across the 1K-ohm emitter resistor with the positive lead to lug 12 and measure the ac and dc output voltages again. Turn the equipment off and answer the Statement.

.15
4.2 DC,
4.5 DC
.34 AC

Statement No. 47: When I connected a bypass capacitor across the emitter resistor, the

[✓ *(1)*] *gain increased and the dc voltage remained the same.*

(2) gain decreased and the dc voltage was unchanged.

(3) gain increased and the dc voltage increased.

EXPERIMENT 48

Purpose: To demonstrate L-C oscillator circuits.

Introductory Discussion: Oscillator circuits are used in nearly all types of electronic apparatus to generate ac signals. These oscillator circuits can be divided according to the frequency of operation (audio or rf) and according to what is used to establish the frequency. In an L-C oscillator, a resonant circuit made up of inductance and capacitance determines the output frequency. In an R-C oscillator of the type you will study later, the frequency is determined by R-C time constants.

All oscillator circuits are basically amplifier circuits in which some of the energy from the output of the stage is fed back to the input. If we place a resonant circuit between the output and the input of an amplifier stage, and the circuit is excited by the amplifier, an ac signal will be produced across the resonant circuit. If some path is provided so that a portion of the output energy can be fed back to the input of the amplifier stage, oscillation will be produced. The stage will continue to oscillate because the energy in the resonant circuit will be constantly reinforced by the amplified output voltage variations. This is illustrated in Fig. 48-1. Fig. 48-1A shows an rf amplifier. The signal across the resonant circuit is fed to the base and the amplified current

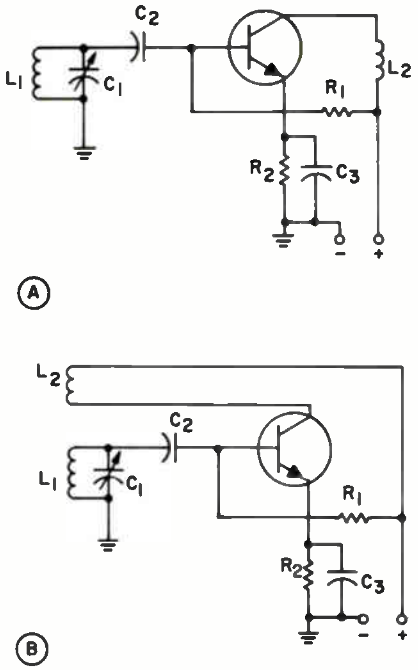


Fig. 48-1. An rf amplifier with coil L_1 in the base circuit and coil L_2 in the collector circuit, (A); an rf oscillator obtained by coupling the collector coil to the base coil, (B).

produces a larger signal voltage across the collector load inductance L_2. If no signal is present across the resonant circuit there will be no variation in collector current and no signal voltage across the collector load.

If, however, the collector load inductance is placed so its magnetic field cuts the turns in the tank inductance, the tank circuit will be shock-excited and will go into oscillation at its resonant frequency. A voltage at this frequency will be set up across the tank. Ordinarily, only a few cycles of voltage would be produced and the oscillation would quickly die out. But in this case the signal is applied to the transistor and the amplified signal current flowing in the collector load induces more voltage into the tank and the circuit continues to oscillate. Fig. 48-1B shows a practical oscillator circuit such as we have described.

As you already know and will prove in this experiment, the feedback must be of the correct phase to reinforce the signal in the tank circuit. If the feedback connections are reversed, oscillation will cease.

In this experiment you will build and test several widely used rf oscillator circuits. You will begin with circuits using inductive feedback and then work with circuits using capacitive feedback.

Experimental Procedure: For this experiment, you will need the experimental chassis, your tvom and the following parts:

1	**Oscillator coil (CO43)**
1	**470-ohm resistor**
1	**1K-ohm resistor**
1	**2.2K-ohm resistor**
1	**100K-ohm resistor**
2	**.001-mfd disc capacitors**
1	**.002-mfd disc capacitor**
1	**250-pf mica capacitor**

Prepare the chassis for this experiment by removing the resistors and capacitors attached to circuit board EC25. Also, disassemble the ac voltage divider connected to terminal strip C. Loosen the screw at hole U, turn the terminal strip around to its previous position and retighten the screw. Remove the 1K-ohm potentiometer and mounting bracket from the chassis.

Mount the oscillator coil on top of the front chassis rail at holes AG and AH as

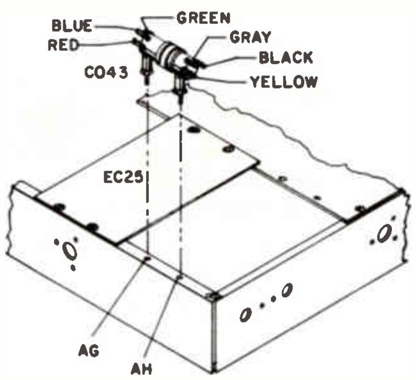


Fig. 48-2. Mounting the oscillator coil.

shown in Fig. 48-2. Remove one nut from each mounting screw on the coil, position the coil so that the terminals color-coded green, blue and red are toward the circuit board and slip the mounting screws through the holes. Attach and tighten the nuts you just removed.

When making connections to the coil, be careful to avoid touching the windings with your soldering iron, as the coil will be damaged.

Construct the circuit shown in the schematic in Fig. 48-3. Connect a 2.2K-ohm resistor from lug 12 of the circuit board to a convenient ground point. Connect a 100K-ohm resistor from lug 11 of EC25 to lug 5 of EC24. Connect a length of hookup wire from lug 1 of EC25 to the terminal color-coded blue on the oscillator coil. Connect a length of hookup wire from the red terminal of the oscillator coil to lug 5 of EC24. Connect a .001-mfd disc capacitor from the green terminal of the oscillator coil to lug 11. Connect a 250-pf mica capacitor between the green and black terminals of the coil. Connect a length of hookup wire from the black terminal of the oscillator coil to ground. Check your wiring against the schematic and make sure all connections are soldered.

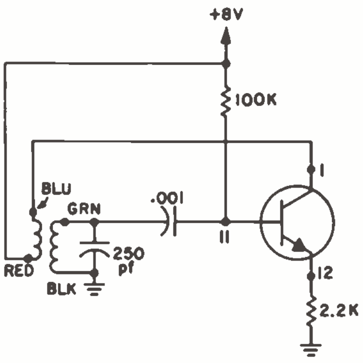


Fig. 48-3. An oscillator circuit using a tickler coil for feedback.

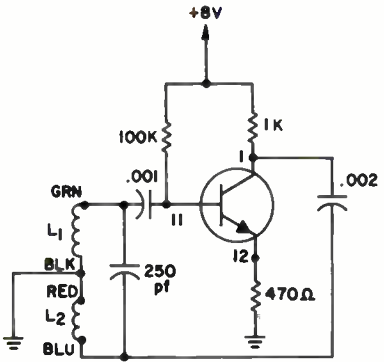
Step 1: To demonstrate a simple L-C oscillator circuit.

Energize the circuit and check to see if it is oscillating. To do this, measure the ac voltage between the collector of the transistor, lug 1, and ground. Any reading greater than about .5V is a pretty good indication that the circuit is oscillating.

Move the probe of your tvom to the green terminal of the oscillator coil and read the ac voltage across the resonant circuit. A reading of 4 to 6 volts ac is normal. Note that this is the voltage across the resonant circuit formed by the green-black winding and the 250-pf capacitor.

Step 2: To prove that in-phase feedback is necessary to sustain oscillations.

Turn the circuit off and unsolder and reverse the connections to the red and blue terminals of the oscillator coil. This change will reverse the phase of the voltage induced into the base circuit



Hartley

Fig. 48-4. The circuit used for Step 3.

winding from the collector. Energize the circuit and check for ac voltage between the collector and ground. Your reading should be zero. Turn the circuit off.

Step 3: To demonstrate an oscillator circuit having feedback through a tapped inductance.

For this step, you will construct a Hartley oscillator circuit. Wire the circuit shown in Fig. 48-4. Unsolder and disconnect the lengths of wire from the red and blue terminals of the oscillator coil. Unsolder and remove the 2.2K-ohm resistor and replace it with a 470-ohm resistor. Connect a 1K-ohm resistor between lug 1 of EC25 and lug 5 of EC24. Connect the red and black terminals of the coil together using a short length of wire.

Move the lead of the 250-pf capacitor from the black terminal to the blue terminal of the coil. Solder a .002-mfd capacitor between lug 1 of EC25 and the blue coil terminal. If necessary, connect a piece of wire to the capacitor lead. Check over your wiring to be sure it is correct.

Energize the circuit and measure the ac output voltage at the collector. Record the value in the chart in Fig. 48-5. You should read 1 volt or more, indicating that the circuit is oscillating.

Next, measure the voltage across the resonant circuit, L_1 and L_2: clip the tvom ground lead to the blue terminal and touch the probe to the green lead of the oscillator coil. Record your reading in the chart. Measure and record the feedback voltage. This is the voltage across the blue-red winding, L_2, of the rf transformer. Then measure and record the voltage across L_1, the green-black winding. Note that the two voltages add, producing approximately 4 volts across the entire resonant circuit which consists of the two windings and the 250-pf capacitor.

Turn the circuit off.

MEASUREMENT	VOLTAGE
OUTPUT	.7
ACROSS L_1 AND L_2	3.5
ACROSS L_2	.38
ACROSS L_1	3.0

Fig. 48-5. Chart for Step 3.

Step 4: To demonstrate an oscillator circuit using capacitive feedback.

You will now construct the Colpitts oscillator circuit shown in the schematic in Fig. 48-6. Unsolder and remove the .002-mfd and 250-pf capacitors and the lengths of wire connected to the red, blue and black terminals of the oscillator coil. Connect a .002-mfd capacitor between the green terminal of the coil and ground. Connect a .001-mfd capacitor between

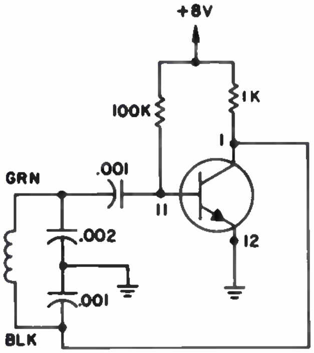


Fig. 48-6. The Colpitts oscillator for Step 4.

the black terminal of the coil and ground. Complete the wiring according to the schematic. Check your work carefully and solder all connections.

Energize the circuit and check for oscillation. You should measure about 1V ac between the collector and ground. Measure the ac voltage across the oscillator coil. A reading of 4V is normal. Now measure the ac voltage at the input to the transistor, between lug 11 and ground. Notice that it is lower than the signal at the collector.

Turn the equipment off.

Discussion: When you reversed the connections to the feedback coil, you found that the oscillator did not work. The feedback was out-of-phase with the voltage across the resonant circuit and cancellation occurred. In-phase feedback is necessary for any oscillator to work.

In Step 3, you built and tested a Hartley oscillator which uses a "tapped" inductance for feedback. By connecting the two windings of the coil in series, you simulated a single-tapped coil. The feedback signal was developed across the blue-red winding. This induced a larger voltage in the green-black winding. The two voltages are in series and add, as you can see in your chart in Fig. 48-5. The total voltage was applied to the base of the transistor.

The circuit in Fig. 48-4 is called a shunt-fed Hartley oscillator. This simply means that the ac and dc circuits of the oscillator are separated so that no dc flows in the oscillator coil, L_1 and L_2.

In Step 4, you experimented with a conventional Colpitts oscillator. The circuit uses "tapped" capacitance in its feedback path. The tapped capacitance consists of two capacitors connected in series, with the center point grounded. The feedback signal is applied through the coil and series capacitors to the base circuit to sustain oscillations. The capacitors are series-connected, and, as you already know, the net value of series-connected capacitors is less than the value of the smaller capacitor. This equivalent capacitance resonates with the coil to establish the oscillator frequency.

You can expect to find variations of these oscillator circuits in electronic equipment. For example, here we used common emitter amplifier configurations. You are sure to find both common base and common collector circuits.

Instructions for Statement No. 48: For this Report Statement, you will take dc voltage readings in the circuit you used in Step 4, first with the oscillator operating and then with it stopped. No additional wiring will be needed.

Turn the circuit on and measure the dc collector voltage and the dc base voltage. Note your readings in the margin. Then, turn the circuit off and unsolder one lead of the .001-mfd capacitor from the green terminal of the coil. Energize the circuit and repeat the voltage measurements.

+54
DC
-.02
DC
+5.2
+6.6

You should now have enough information to answer the Statement. Turn the equipment off and answer the Statement here and on the Report Sheet.

Statement No. 48: When I stopped the oscillator circuit in Fig. 48-6 by disconnecting the .001-mfd capacitor, I found that the base voltage:

[✓ *(1)*] *became more positive*
(2) became less positive
(3) did not change appreciably

and the collector voltage

(1) became more positive.
[✓ *(2)*] *became less positive*
~~*(3)*~~ *did not change appreciably.*

EXPERIMENT 49

Purpose: To show that two amplifier stages can be connected to form an R-C oscillator; to show how feedback controls the stages and to observe the voltage variations.

Introductory Discussion: In the previous experiments, we examined current flow in transistors and examined bias arrangements in amplifier stages. We also demonstrated the operation of L-C oscillator circuits. We will now construct two amplifier stages and connect them to form an oscillator circuit called an "astable" or "free running" multivibrator. The two amplifiers are connected so that they conduct alternately and each one controls the other. As one transistor cuts off, it turns on the other so that the second transistor conducts heavily.

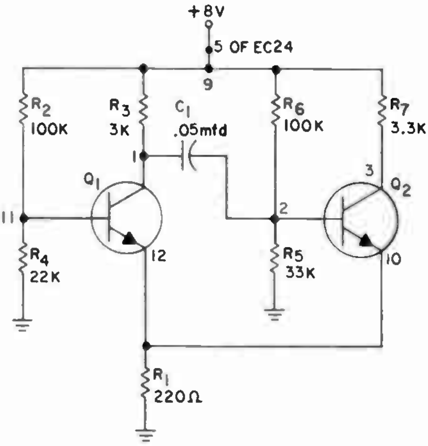


Fig. 49-1. The emitter-coupled multivibrator circuit used in Step 1.

The circuit you will use is the emitter-coupled multivibrator circuit shown in the schematic in Fig. 49-1. Let's briefly describe how the circuit works. When power is first applied to the circuit, both transistors begin to conduct. Initially, however, one will always conduct more heavily than the other.

Let's assume that transistor Q_2 conducts more heavily. Current flows from ground through resistor R_1 to both emitters. In each transistor, the current divides, with part going to the base and through the base bias resistor (R_2 or R_6) and the remainder flowing into the collector circuit and through the collector load resistor (R_3 or R_7) to the positive voltage supply. The current through R_1 produces a voltage drop which makes the emitters positive and tends to reverse bias the base-emitter junctions of both transistors. As the total current increases, the emitter voltage increases. The emitter voltage reaches a level where transistor Q_1 begins to cut off as its base becomes less positive with respect to its emitter. The Q_1 collector voltage rises toward the supply voltage, causing capacitor C_1 to charge.

The charge path is through the Q_2 base circuit, causing current flow from ground up through resistor R_5. This makes the base of Q_2 more positive and Q_2 conducts even more. As C_1 becomes fully charged, the current through R_5 decreases and the voltage drop across R_5 decreases. Therefore, the bias on Q_2 decreases and it conducts less, producing a smaller voltage drop across R_1.

When the R_1 voltage drop falls below a certain level, Q_1 will begin to conduct and its collector voltage will begin to drop. C_1, which has charged to the high Q_1 collector voltage, will then begin to discharge. It discharges through R_5 and R_6 to ground and +8, through R_1 and the emitter-collector path of Q_1. Note that now the current through R_5 and R_6 makes the base of Q_2 negative. Hence, Q_2 is cut off.

After C_1 has discharged enough, the reduced discharge current will allow Q_2 to conduct again. As before, the forward bias is supplied by R_6. Q_2 will begin to conduct and the next cycle will begin.

The multivibrator is one of the most useful circuits in electronics. It is used in the horizontal and vertical deflection circuits of TV receivers, in transmitter control equipment, in test equipment and in computers. Frequency of operation can be as low as a few Hertz or as high as several megahertz. The circuits you will build have a maximum frequency of slightly less than 1 kHz.

Experimental Procedure: For this experiment you will need your tvom, the experimental chassis and the following parts:

1	220-ohm resistor
1	470-ohm resistor
1	3K-ohm resistor
1	3.3K-ohm resistor
1	22K-ohm resistor
1	33K-ohm resistor
2	100K-ohm resistors
1	.05-mfd capacitor
1	100-mfd, 10V elect. capacitor

Before proceeding with this experiment, you will construct the multivibrator circuit shown in Fig. 49-1. First unwire the circuit used in Experiment 48 but leave the transistor on the circuit board. Remove the coil from the chassis.

You will need two transistors for this experiment. Locate a second NPN transistor among the parts you received in this kit and identify the leads. Refer to the sketch in Fig. 49-2. Mount the transistor on the circuit board (EC25) at the location shown in Fig. 49-2. Mount it in the same manner as the transistor already on the board. Melt a little solder for each connection, use your pliers as a heat sink and solder each lead carefully. Check carefully to see that the collector con-

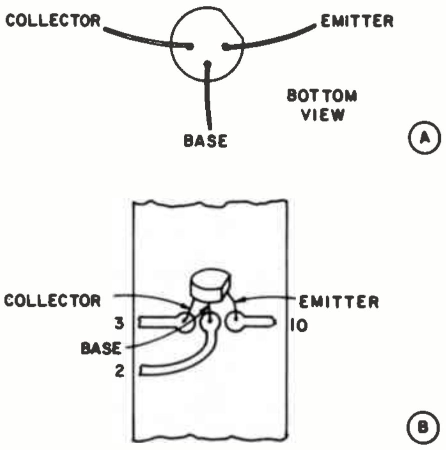


Fig. 49-2. Mounting the second NPN transistor on the circuit board.

nects to lug 3, the base connects to lug 2, and the emitter connects to lug 10.

In wiring the multivibrator circuit, the leads of the component parts can either be soldered to the terminal lugs or to the copper foil strips, as mentioned earlier. Do not cut the leads of the components, but bend the leads as necessary to make the connections.

Wire the circuit shown in Fig. 49-1. You can use lug 9 of EC25 as a tie point for some of the connections to the +8V source. Connect a 22K-ohm resistor between lug 11 and ground; connect a 220-ohm resistor between lug 12 and ground; and connect a 33K-ohm resistor between lug 2 and ground.

Connect a 100K-ohm resistor between lugs 9 and 11; connect a 3.3K-ohm resistor between lugs 3 and 9; connect a 100K-ohm resistor between lug 2 of EC25 and lug 5 of EC24; and connect a 3K-ohm resistor between lug 1 of EC25 and lug 5 of EC24.

Connect a .05-mfd disc capacitor between lugs 1 and 2; connect a length of hookup wire between lugs 10 and 12; and connect a length of wire between lug 9 of EC25 and lug 5 of EC24. Check your wiring and solder all connections. Bend the leads of the parts so that there are no short circuits.

Step 1: To show that the multivibrator circuit produces oscillations.

Set your tvom to measure 3 volts ac and turn the circuit on. Connect the tvom ground clip to the chassis, touch the probe to lug 3 and measure the ac voltage at the collector of transistor Q_2. Record the value in the space provided for Q_2 in the chart in Fig. 49-3. If you read no ac voltage, recheck your circuit to be sure it is wired correctly.

	AC	DC
Q_1 COLLECTOR	.5V	5.4
Q_1 BASE	.14V	.95
Q_2 COLLECTOR	2.65V	5.2
Q_2 BASE	.44V	.63
EMITTERS	.15V	.32

Fig. 49-3. The chart for use in Step 1.

Move the tvom probe to lug 1 and measure the ac voltage at the collector of Q_1. Record this value in the chart also. Measure and record the ac voltages at each of the points listed in the chart in Fig. 49-3.

When you complete your ac readings, go back and take the dc voltage readings at each of the 5 points in the circuit and record your readings.

Step 2: To show voltage variations in the multivibrator circuit.

Turn the circuit off and connect a 100-mfd, 10V electrolytic capacitor in place of the .05-mfd capacitor in your circuit. Connect the positive lead to lug 1 and the negative lead to lug 2. Turn the circuit on and measure the dc voltage at the collector of transistor Q_2.

You will notice first that the voltage varies from the supply voltage of about +8 volts to 0 and back again. By increasing the value of the coupling capacitor (C_1 in Fig. 49-1), you have slowed down the operation of the oscillator to the point where the dc voltmeter is nearly able to follow the voltage variations.

Note that the voltage rises sharply, remains at its maximum value for a time, falls sharply and stays near zero for a while. If you were to graph this voltage variation with respect to time, you would have a voltage waveform similar to the one shown in Fig. 49-4A.

Move the probe to the collector of Q_1 and observe the dc voltage there. You will see that this voltage varies at the same rate as the Q_2 collector voltage, but over a very narrow range. The nominal variation is from 3.5 to 5.5 volts. The transitions are not as sharp as those at the collector of Q_2. However, the waveform is said to be a rectangular wave. It is shown in Fig. 49-4B.

Set the range switch to 3V and touch the probe to the base of Q_2 (lug 2). You will see that the voltage varies by about 1 volt. Actually, it swings positive and negative. The voltage goes slightly negative and becomes positive again so quickly that the meter may not show it. Consequently you may not see the pointer move to the left of zero. The Q_2 base waveform is shown in Fig. 49-4C.

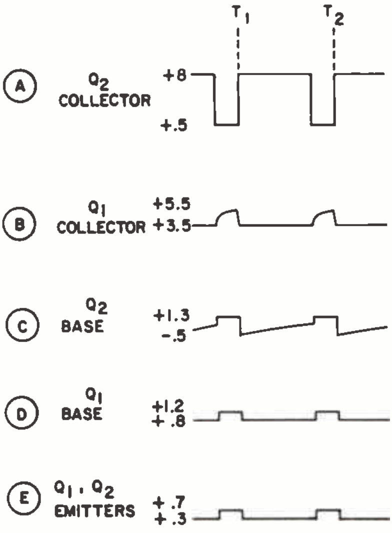


Fig. 49-4. Waveforms in the multivibrator circuit.

With your voltmeter, verify that the waveforms shown in Figs. 49-4D and E occur at the base of transistor Q_1 and at the emitters at both transistors. Note that these voltages vary over a very narrow range and that they are in step with the other voltages.

Step 3: To demonstrate the feedback paths in the multivibrator circuit.

Turn the circuit off and replace the 100-mfd capacitor with the .05-mfd capacitor shown in Fig. 49-1. Turn the circuit on and check for ac voltage at lug 3. The ac voltage will tell you that the circuit is oscillating.

Solder the negative lead of the 100-mfd electrolytic capacitor to a ground point near lug 12. While observing the ac voltage at lug 3, touch the positive lead of the electrolytic capacitor to lug 12. The capacitor places lug 12 at ac ground. Note its effect on the oscillation. Remove the 100-mfd capacitor.

Turn the circuit off and unsolder one lead of the .05-mfd coupling capacitor. Energize the circuit and measure the ac voltage at lug 3. There should be none, indicating that the circuit is not oscillating. Turn the circuit off. Replace the .05-mfd capacitor with the 100-mfd capacitor. Be sure to connect the positive lead to lug 1.

Discussion: In this experiment you demonstrated that two transistor amplifiers can be coupled together to form an oscillator. This is termed an R-C oscillator to distinguish its general type from the L-C oscillators you used in the previous experiment.

In Step 1 you proved that the circuit was oscillating by the fact that you were able to measure ac voltages in the circuit.

The ac voltages are actually the ac components of pulsating dc voltages, with the exception of the voltage at the base of transistor Q_2 which goes negative during each cycle.

Refer to your chart in Fig. 49-3. The ac voltage at the collector of Q_2 should be higher than the ac voltage anywhere else in the circuit. The ac at the collector of Q_1 should be between one third and one half of the Q_2 collector ac voltage. Typically, the ac at the base of Q_2 is under .5V and the ac at the base of Q_1 and at the emitters was too low to measure.

Now look at the dc voltages. The Q_1 collector voltage should be about 6V and the Q_2 collector voltage should be about 4V. The average conduction of Q_1 is higher than that of Q_2. Thus the average voltage drop across its collector load resistor (R_3) is higher. Similarly, the Q_1 base voltage should be more positive than the Q_2 base voltage. Both should be between .5V and 1V. It may appear that there is insufficient forward bias on the transistors. This is an illusion created by the fact that the meter gives average voltage indications.

In Step 2 you observed the wave shapes in the circuit with the oscillator operating at a very low frequency. Your observations should be very similar to the waveforms shown in the graph in Fig. 49-4.

You should have found that transistor Q_2 is alternately cut off and saturated. Cutoff is indicated by high collector voltage when there is hardly any voltage drop across the collector load resistor. When the transistor is saturated, the collector voltage is nearly zero due to the large current through the collector load and the large voltage drop across it.

This variation in collector voltage is caused primarily by the base voltage. You saw that the base was reversed biased during part of the cycle and highly forward biased during the remainder of the cycle. Thus the transistor conduction varied widely.

Transistor Q_1 acted basically as a common base amplifier as the input signal was applied to its emitter and the output was taken from its collector. As you saw, the Q_1 collector voltage varied by only 2 volts or so. This, however, was sufficient to initiate the charging and discharging of the coupling capacitor.

As we mentioned earlier, the charging and discharging of the coupling capacitor establishes the voltage drop across resistors $\mathbf{R_5}$ and $\mathbf{R_6}$ and, consequently, the voltage at the base of Q_2. Thus when we increased the amount of capacity, we increased the period of each cycle proportionately.

From earlier studies you know that the frequency of a signal is equal to the reciprocal of its period: $F = 1/P$. Then, if we increase the time required for the capacitor to charge and discharge, we decrease the frequency. To determine the frequency, count the number of complete cycles which occur in a given unit of time. If each cycle takes longer than a second, it is most convenient to express the frequency in cycles-per-minute.

In Step 3 you should have found that the oscillations stopped when you placed the capacitor across the emitter resistor and when you disconnected the coupling capacitor. In both cases you disabled the feedback. It is necessary for both feedback loops to pass signals so that each amplifier will be controlled and will be able to control the other.

In connecting the capacitor across the

emitter resistor, you placed the emitters at signal or ac ground potential. Thus variations in the conduction of Q_2 were not applied to the emitter of Q_1 so Q_1 could not cause C_1 to charge and discharge. When you opened the coupling capacitor, you prevented any voltage variations at the Q_1 collector from reaching the base of Q_2.

Instructions for Statement No. 49: For this Statement you will increase the value of the emitter resistor and note its effect on the oscillator frequency. With the 100-mfd coupling capacitor in the circuit, observe the Q_2 collector voltage and determine the frequency of the oscillations. To do this, count the number of oscillations taking place in 1 minute. One cycle is the period, for example, between T_1 and T_2 of the collector waveform in Fig. 49-4A. Watch your voltmeter and note the number of times the collector voltage jumps to +8 volts (T_1). The voltage will then drop. Use a watch or clock having a sweep second hand to measure the time accurately.

Turn the circuit off, disconnect the 220-ohm resistor from lug 12 and connect a 470-ohm resistor in its place.

14 Turn the circuit on, connect the voltmeter to lug 3 and again determine the frequency of oscillation. Compare this frequency with the frequency produced with the 220-ohm emitter resistor. Answer the Statement here and on the Report Sheet and turn your equipment off. 11

Statement No. 49: When I increased the emitter resistor value from 220 ohms to 470 ohms, the oscillator frequency:

(1) increased.
[✓ *(2) decreased.*]
(3) remained the same.

EXPERIMENT 50

Purpose: To show that the gain of a cascade amplifier is greater than the gain of a single amplifier stage and to compare AC and DC coupling in cascade amplifier stages.

Introductory Discussion: There are very few applications where a single stage of amplification is used. Usually amplifier stages are connected in cascade to increase the overall gain or amplification which the signal receives. Typical examples are the audio, i-f and video sections of a TV receiver and the audio section of a radio receiver. Each of these amplifier sections consists of from 2 to 4 stages cascaded together.

Amplifier stages may be coupled together by several different methods. In this experiment, we will concern ourselves with common emitter stages, resistance-capacitance (R-C) coupling and direct current (DC) coupling. As the names imply, R-C coupling consists of a coupling capacitor connected between the stages in such a way that only the ac component signal is transferred. In DC coupling, usually a direct wire or a resistor is connected between the two stages. However, diodes can also be used. As such, the dc reference level, as well as the signal, is coupled from the first stage to the second. Of the two methods, R-C coupling is more widely used, and DC coupling is used for special purposes.

In this experiment, you will first construct a two-stage amplifier with R-C coupling. After measuring gain and dc voltages, you will rewire the circuit for DC coupling and carry out additional steps.

Experimental Procedure: For this experiment, you will need the experimental chassis with the two circuit boards mounted, your tvom, and the following parts:

- 1 10-ohm resistor
- 1 220-ohm resistor
- 1 330-ohm resistor
- 1 470-ohm resistor
- 1 2.2K-ohm resistor
- 1 3.3K-ohm resistor
- 1 4.7K-ohm resistor
- 1 15K-ohm resistor
- 1 18K-ohm resistor
- 2 100K-ohm resistors
- 1 10-mfd electrolytic capacitor
- 1 6-mfd electrolytic capacitor
- 2 HV silicon diodes

The HV diodes are in the HV power supply circuit. Temporarily remove them from terminal strip A on your chassis.

Dismantle the circuit used for Statement 49, but leave the two transistors on the circuit board. Also leave the 3.3K-ohm resistor connected between lugs 3 and 9, leave the 100K-ohm resistors in place, and leave the length of hookup wire between lug 9 and lug 5 of EC24.

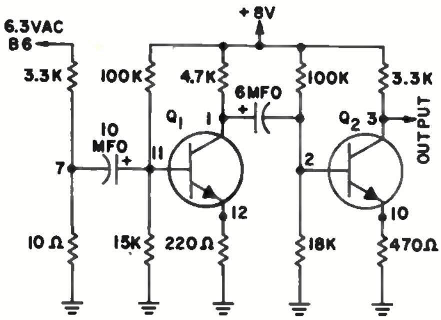


Fig. 50-1. The ac voltage divider and R-C coupled amplifier.

Wire the ac voltage divider and 2-stage amplifier circuit shown in the schematic diagram in Fig. 50-1. Connect a 3.3K-ohm resistor between terminal B6 and lug 7 of EC25. Connect a 10-ohm resistor from lug 7 to ground. Connect a 10-mfd electrolytic capacitor from lug 7 to lug 11. The positive lead connects to lug 11. Connect a 15K-ohm resistor between lug 11 and ground. Connect a 220-ohm resistor from lug 12 to ground. Connect a 470-ohm resistor from lug 10 to ground. Connect an 18K-ohm resistor between lug 2 and ground.

Connect a 4.7K-ohm resistor from lug 1 of EC25 to lug 5 of EC24. Connect a 6-mfd electrolytic from lug 1 to lug 2, with the positive lead going to lug 1.

Your circuit should now be wired according to the schematic in Fig. 50-1. Check your work and make sure all connections are soldered.

Step 1: To measure the voltage gains in an R-C coupled amplifier circuit.

As in previous work, you will use the 60 Hz ac filament voltage as your signal. The voltage divider, consisting of the 3300-ohm resistor and the 10-ohm resistor, gives an output of approximately .02V. We will use the value .02V in the discussion as the input signal voltage throughout this experiment.

With your tvom set to read ac voltage, touch the probe to lug 11 and note that the input voltage is too low to read on your meter. Move the probe to lug 1 and read the ac output voltage of the first stage at the collector. Record your reading in the space for the "stage 1 output" in the chart in Fig. 50-2.

.24

Now measure the input to stage 2 at the base connection, lug 2. The reading

.24

12.
.02).24
2
4

should be very close to the previous reading, as the large coupling capacitor has extremely low impedance at the signal frequency. Record this value in the space for the "stage 2 input" in Fig. 50-2.

2 4
8
5 2
4
7
.8

Measure the stage 2 output voltage at lug 3. This point is the collector of transistor Q_2. Record the output in the chart.

	INPUT	OUTPUT	GAIN
STAGE 1 Q_1	.02	.24	12
STAGE 2 Q_2	.24	1.6	≃7

27.
.24)1.60

Fig. 50-2. Chart for Step 1.

Using the information in the chart, compute the voltage gain of each stage and record it in the proper place in the chart. Use the formula,

80.
.02)1.600

$$\text{voltage gain} = \frac{\text{output voltage}}{\text{input voltage}}$$

Now compute the overall gain of the two-stage amplifier. Use the same formula, but divide the Q_2 output by the Q_1 input of .02 volts. Jot down the results of this computation in the margin and compare it with the individual stage gains. You can readily see that the overall gain is the product of the individual stage gains.

Step 2: To show that the amplifier does not provide DC coupling.

Measure the dc voltage at the base of transistor Q_1 and record it in the chart in Fig. 50-3A. In a similar manner, measure and record the dc voltages at the other three points listed in Fig. 50-3A.

TEST POINT	Q_1	Q_2
BASE	.36	1.0
COLLECTOR	5.6	5.1

Ⓐ

TEST POINT	Q_1	Q_2
BASE	0	1.1
COLLECTOR	7.9	5.2

Ⓑ

Fig. 50-3. Chart for dc voltages (A) with signal and (B) with input shorted.

Solder a length of wire between ground and lug 11 and repeat the dc voltage measurements. Record the reading in Fig.50-3B. The short-circuited input represents a negative change in the dc voltage at the input to the amplifier. You should find that some of the voltage readings change very little if at all. Remove the short from the input.

Step 3: To measure the gain of a DC coupled cascade amplifier.

Turn the circuit off and wire the circuit shown in the schematic in Fig. 50-4. Remove the 6-mfd capacitor. Remove the 18K-ohm and 100K-ohm resis-

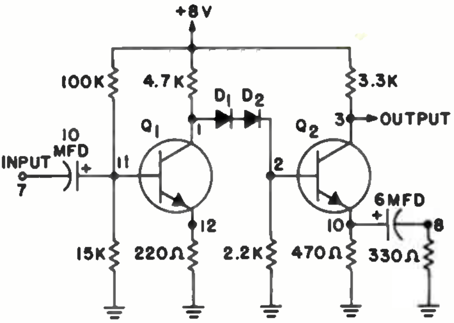


Fig. 50-4. The direct coupled amplifier circuit for Step 3.

tors connected to lug 2. Connect a 2.2K-ohm resistor between lug 2 and ground.

Connect the 2 HV silicon diodes with the anode lead of one soldered to the cathode lead of the other. Now solder the free *anode* lead to lug 1 and solder the free *cathode* lead to lug 2. Connect a 330-ohm resistor between lug 8 and ground. Connect the 6 mfd capacitor from lug 10 to lug 8 with the polarity shown in Fig. 50-4. Note in Fig. 50-4 that the forward bias as well as the signal for the base of Q_2 comes from the Q_1 collector circuit.

Energize the circuit and measure the ac voltages at the collector of Q_1 and at the base and collector of Q_2. Record your readings in the chart in Fig. 50-5. The input signal voltage remains unchanged at .02V.

	INPUT	OUTPUT	GAIN
STAGE 1 Q_1	.02	.04	2
STAGE 2 Q_2	.04	.63	1500

1500.
.04).6300.
4
23

Fig. 50-5. The chart for Step 3.

Compute the gain of each stage and record your results in the chart. Also compute the overall gain of the cascade amplifier. Note this value in the margin.

Step 4: To show DC coupling between amplifier stages.

TEST POINT	Q_1	Q_2
BASE	.72	1.4
COLLECTOR	2.2	1.5

Ⓐ

TEST POINT	Q_1	Q_2
BASE	0	1.6
COLLECTOR	2.5	1

Ⓑ

Fig. 50-6. The chart for dc voltages in Step 4 (A) with signal and (B) with input shorted.

As you did in Step 2, measure the dc voltages at the points in the circuit listed in the chart in Fig. 50-6A, and record them. Then short the input, lug 11, to ground and repeat the measurements with the input shorted. Record your voltage readings in Fig. 50-6B. Turn the equipment off and remove the short from lug 11.

Discussion: The essential facts demonstrated in this experiment are (1) the gain of a cascade amplifier is equal to the product of the individual stage gain, and (2) a DC amplifier passes the dc as well as the ac component of the input signal.

In the first two steps, you used conventional RC coupling between the stages. The voltage variations at the collector of transistor Q_1 caused the coupling capacitor to charge and discharge through the Q_2 base circuit. This caused the current through the 18K-ohm resistor in the Q_2 base circuit to vary, and thus a varying voltage was applied to Q_2. Q_2 amplified this signal voltage.

The diodes provided the coupling in Steps 3 and 4. As you have learned, a forward biased silicon diode has a voltage drop of about .6V across itself. The two series connected diodes, therefore, have a net voltage drop of slightly more than 1V. The diodes, therefore, couple both ac and dc voltage from the collector of Q_1

to the base of Q_2. The resistor between the base of Q_2 and ground helps provide the proper bias for the transistor.

In the NRI Laboratory, we realized stage gains of 10 for Q_1 and 8 for Q_2 in Step 1. The product of the two is 80. Our overall gain measurement was equal to 1.6V/.02V which is also 80. In Step 3, the stage 1 gain was 5 and the stage 2 gain was 15, giving a computed overall amplification of about 75. The overall gain was approximately 1.5/.02 or 75.

You saw how both amplifier circuits responded to changes in dc level at the input in Steps 2 and 4. With R-C coupling, only the ac component of the signal is transferred through the amplifier circuit. This is because the coupling capacitor provides dc isolation between stages. In Step 4, however, you found that both stages were affected when you removed the forward bias on Q_1 by shorting its base to ground. The reduction in forward bias cut off Q_1 and caused its collector voltage to rise. This appeared to Q_2 as a positive-going signal, increasing the forward bias on Q_2. The resulting increase in Q_2 collector current produced a greater voltage drop across the Q_2 collector load resistor. Thus, it reduced the output dc level.

Instructions for Statement No. 50: For this Statement, you will simulate a defect in the coupling between the two amplifier stages and note its effect on the gain of the first stage.

Energize the circuit, measure the ac voltage at the collector of Q_1 and compute the gain of the stage. (The input is approximately .02V.) Then turn the circuit off and unsolder the anode lead of D_1 from lug 1.

Turn the circuit on again and measure the ac voltage at the collector of Q_1. Again compute the gain, compare it with the gain before you disconnected the diode, and answer the Statement here and on the Report Sheet.

Turn all equipment off. Remove the HV diodes from the circuit board and reinstall them in the HV power supply circuit as shown in Figs. 5 and 6.

Statement No. 50: When I opened the circuit between the two amplifier stages, I found that the gain of the first amplifier stage:

(1) remained the same.
(2) decreased.
[✓ *(3) increased.*]

CONCLUSION

You have completed the final experiment in this Training Kit. Let's review the important points which you have learned. In the first four experiments, you studied vacuum tubes and vacuum-tube circuits. You learned that a Class A vacuum-tube amplifier requires a bias voltage applied between the grid and cathode. The bias voltage makes the grid negative with respect to the cathode so that both the negative and positive portions of the input signal will control the tube current and be amplified. You also saw that bias voltage can be supplied by a separate bias source, or it can be derived from the signal or from the B+ supply by one of several methods. Finally, you compared the three vacuum-tube amplifier configurations: common cathode, common plate and common grid.

In the latter part of the kit, you worked with transistor circuits. You began with bias and biasing methods and amplifier configurations. Then you constructed and performed experiments on L-C and R-C oscillators and cascade amplifiers.

You learned that in a transistor, the base-emitter junction must be forward biased in order for current to flow from the emitter across both junctions to the collector. Also, the bias voltage can be obtained from an external bias source or from the collector supply voltage in the circuit. In the experiment on transistor amplifier configurations, you constructed and compared the gain and impedance characteristics of the three amplifier configurations: common emitter, common base and common collector.

L-C and R-C oscillators were taken up after the work with amplifier fundamentals. You learned that an oscillator must have amplification and feedback. Also, you learned that in an L-C oscillator, the frequency is established by the resonant frequency of a resonant circuit while in an R-C oscillator, the frequency is set by the time constant of an R-C network.

In the final experiment, you built a cascade amplifier and saw that its overall gain is the product of the individual stage gains and that either R-C or DC coupling can be used.

LOOKING AHEAD

In the next Training Kit, you will continue your study of practical circuits and electronics fundamentals. You will

1	.1-mfd tubular capacitor
2	.25-mfd tubular capacitors
1	20-mfd electrolytic capacitor
2	.001-mfd disc capacitors
1	.002-mfd disc capacitor
1	.05-mfd disc capacitor
1	250-pf mica capacitor
1	6-mfd electrolytic capacitor
1	100-mfd electrolytic capacitor
1	Experimental chassis w/2 etched circuit boards
2	Alligator clips
1	1K-ohm potentiometer
1	10-ohm resistor
1	47-ohm resistor
1	220-ohm resistor
1	330-ohm resistor
1	470-ohm resistor
1	680-ohm resistor
2	1K-ohm resistors
2	2.2K-ohm resistors
1	3K-ohm resistor
2	3.3K-ohm resistors
2	4.7K-ohm resistors
1	6.8K-ohm resistor
1	10K-ohm resistors
1	15K-ohm resistor
1	18K-ohm resistor
2	22K-ohm resistors
1	33K-ohm resistor
2	47K-ohm resistors
2	100K-ohm resistors
1	220K-ohm resistor
1	330K-ohm resistor
1	470K-ohm resistor
1	1-megohm resistor
1	1.8-megohm resistor
2	10-megohm resistors
1	12BA6 tube
1	12AT6 tube

Table I. Leftover parts to be stored for later use.

take up modulation, detection, rf amplification and other principles related to radio transmission and reception.

Be sure to complete your Report Sheet and send it in for grading. While you are waiting for your grade, prepare the chassis for the next kit. Remove all resistors and capacitors from the experimental circuit board (EC25). Leave the low-voltage power supply wired up on circuit board EC24, and leave the two transistors in place on EC25. Clean off all leads and terminals, using the technique which you learned earlier.

Table I lists the parts you should have left over. It does not include the parts mounted on the experimental chassis or on the two circuit boards.

WHEN YOU WORK FOR A MAN

Here are some words of advice written by Elbert Hubbard. Whether you are an employer or employee, I believe you'll want to read this over several times:

"If you work for a man, in heavens's name work for him. If he pays wages that supply you your bread and butter, work for him, speak well of him, think well of him, stand by him, and stand by the institution he represents. I think if I worked for a man, I would work for him, I would not work for him a part of his time, but all of his time. I would give an undivided service or none. If put to a pinch, an ounce of loyalty is worth a pound of cleverness. If you must vilify, condemn, and eternally disparage, why, resign your position, and when you are outside, damn to your heart's content. But, I pray you, so long as you are a part of an institution, do not condemn it. Not that you will injure the institution – not that – but when you disparage the concern of which you are a part, you disparage yourself."

John G. Champion

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6T

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PRACTICAL DEMONSTRATIONS
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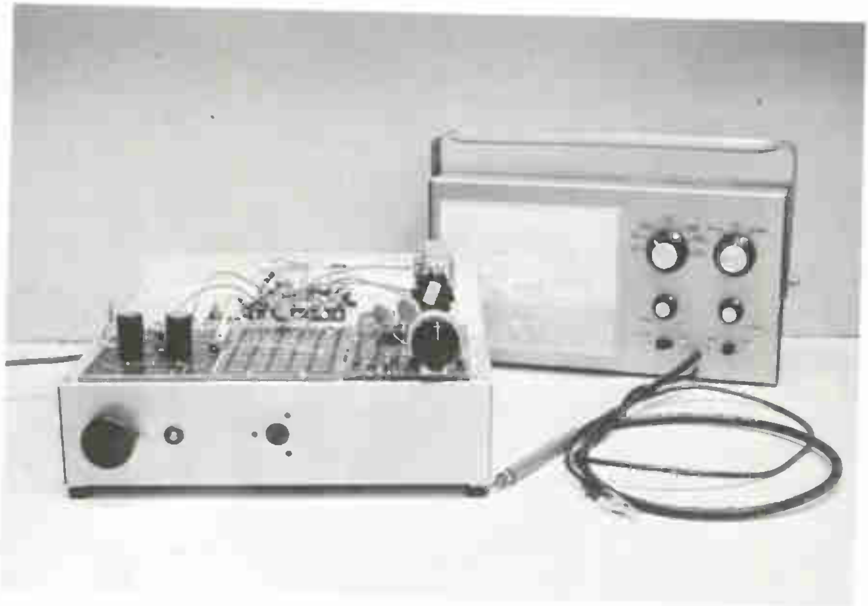


INDEX OF SECTIONS

CEC5C1075 1975 EDITION Litho in U.S.A.

INSTRUCTIONS FOR PERFORMING EXPERIMENTS 51 THROUGH 60

In your last series of experiments, you conducted experiments with transistor and vacuum tube amplifiers and oscillators. You are now ready to conduct experiments on typical circuits which you will encounter in future training kits and in your work as a technician. You will continue work with amplifiers and oscillators and we will show you how these circuits are used in electronic equipment for home entertainment.

This kit is divided basically into two parts: Audio Frequency and Radio Frequency. In the Audio Frequency section, you will begin with loudspeakers and audio amplifiers. In these experiments, you will learn how loudspeakers work and you will study typical audio amplifier circuits. Then you will perform an experiment using the field-effect transistor. Following this, you will perform an experiment on a stereo indicator circuit.

In the rf section of the kit, you will construct an rf oscillator circuit and use it to demonstrate i-f amplifier and limiter stages and AM and FM demodulator circuits.

Be careful as you construct the circuits for these experiments to avoid short-circuits and wiring errors. Locating such troubles can be time-consuming and it is usually unnecessary. Extra care is needed because the circuits are more complex, containing many parts and wires.

Wiring from the schematic diagrams usually works best. However, some help is given in the form of sketches and written instructions. Use the extra help if you need it. Remember, however, a good technician should be able to work from the schematic diagram alone.

If you have trouble with any experiment, look the circuit over carefully to make sure there are no poorly soldered connections or wiring errors. Make voltage and resistance measurements and, if you need help, write, telling us what tests you have made and your test results. Use the special kit consultation blank enclosed for all questions concerning the experiments in your practical demonstration course.

CONTENTS OF THIS KIT

The contents of this kit are shown in Fig. 1 and listed below the figure. Check the parts you received against this list to be sure you have all the listed parts. Do not discard any of these parts or the parts from previous kits until you have finished your NRI course.

IMPORTANT: If any part in this kit seems to be missing, look for a substitute. If any part is obviously defective, or has been damaged in shipment, return it immediately to NRI as directed on the "Packing and Returned Material" slip included with this kit.

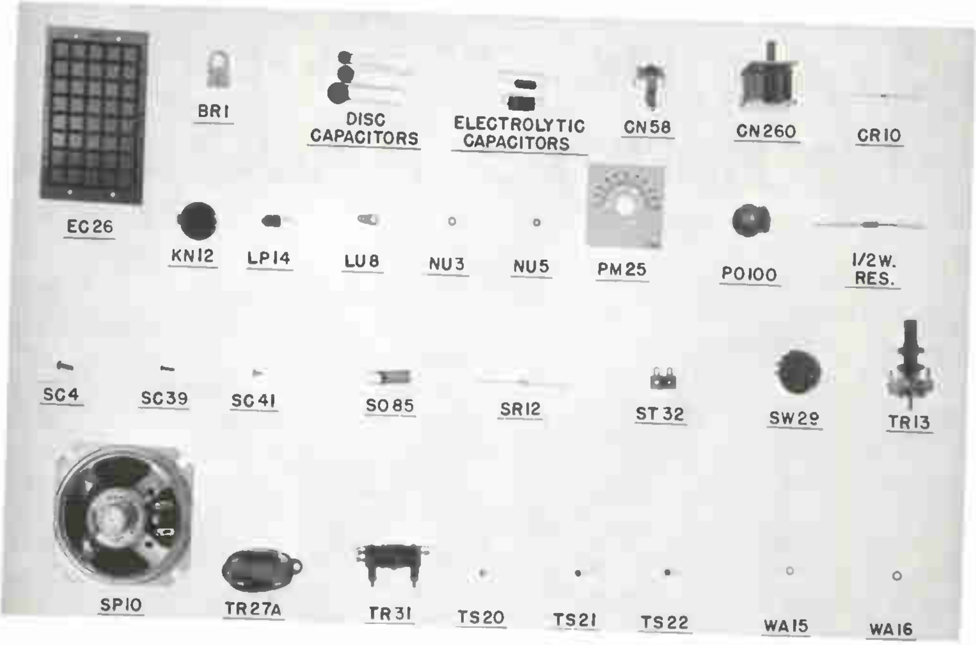


Fig. 1. The parts in this kit are shown above and listed below.

Quan.	Part No.	Description	Price Each
3	BR1	Pot. mounting brackets	.05
4	CN34	.001 mfd disc capacitors	.15
1	CN58	80-480 pf trimmer capacitor	.40
2	CN85	.01 mfd disc capacitors	.16
2	CN95	6 mfd, 20V electrolytic capacitors	.42
3	CN104	0.1-mfd disc capacitors	.36
1	CN202	18 pf disc capacitor	.15
1	CN204	0.05-mfd disc capacitor	.30
2	CN223	470 pf disc capacitor	.15
3	CN245	0.005-mfd disc capacitors	.22
1	CN112	100 mfd, 10V electrolytic capacitor	.45
1	CN260	Variable tuning capacitor	2.46
2	CR10	Silicon signal diodes	.40
2	EC26	Etched circuit boards	1.10
1	KN12	Control knob	.17
1	LP14	No. 49 pilot lamp	.40
2	LU8	Solder lugs	12/.15
2	NU3	8-32 hex nuts	12/.15
8	NU5	4-40 hex nuts	12/.15
1	PM25	Dial scale	.10
1	PO100	50k-ohm pot. w/nut & lockwasher	1.02
2	RE26	100-ohm, 10%, 1/2W resistors	.15
7	RE31	10k-ohm, 10%, 1/2W resistors	.15
1	RE47	150-ohm, 10%, 1/2W resistor	.15

Quan.	Part No.	Description	Price Each
2	RE29	4.7k-ohm, 10%, 1/2W resistors	.15
1	RE50	6.8k-ohm, 10%, 1/2W resistor	.15
2	RE68	150k-ohm, 10%, 1/2W resistors	.15
1	RE72	47-ohm, 10%, 1/2W resistor	.15
2	SC4	3/8" X 8-32 screws	12/.15
5	SC39	3/8" X 4-40 screws	12/.15
3	SC41	3/16" X 6-32 screws	12/.25
1	SP10	Loudspeaker	1.59
1	SO85	Pilot lamp socket	.71
2	SR12	Low voltage silicon rectifiers	.67
1	ST32	2-lug terminal strip	.05
1	SW29	3-position rotary switch	.94
1	TR13	I-F transformer	1.23
1	TR27A	Output transformer	1.25
1	TR31	RF transformer	1.10
1	TS20	Field effect transistor	1.00
1	TS21	NPN silicon transistor (2N5134)	.19
3	TS22	PNP silicon transistors (2N5138)	.19
3	WA15	No. 6 lockwashers	12/.15
2	WA16	No. 8 lockwashers	12/.15

PARTS DATA

The following information should help you to understand some of the special characteristics of certain parts supplied in this kit.

PNP Transistor. You received three small PNP transistors (TS22) in this kit. These are small signal silicon transistors which have high gain and are designed for amplifying weak signals. As you already know, the polarities of the voltages applied to the elements of a PNP transistor are the reverse of those for an NPN transistor. With respect to the emitter, the collector is operated highly negative and the base is slightly negative.

The schematic symbol for the transistor is shown in Fig. 2A. This symbol is different from the NPN symbol only in the direction of the arrow representing the emitter. Fig. 2A also shows the lead identification for the PNP transistor.

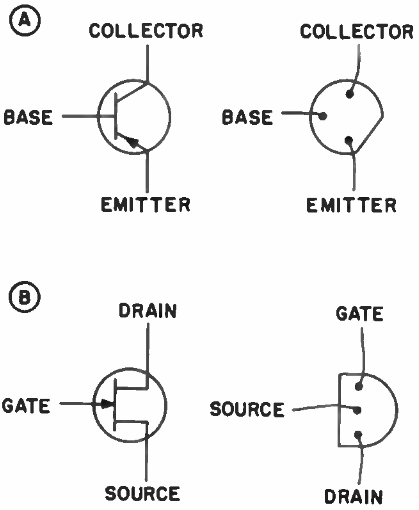


Fig. 2. Schematic symbols and lead identification for (A), the PNP transistor, and (B), the field-effect transistor you will use in this kit.

Field Effect Transistor. This transistor is a silicon N-channel type, solid-state device which physically resembles a transistor, but behaves more nearly like a vacuum tube. You will work with this transistor to discover some of its characteristics. The schematic symbol and lead identification are given in Fig. 2B.

The Tuning Capacitor. The tuning capacitor you received in this kit is a standard receiver type. It has two sets of multiple plates and uses an air-dielectric. The stator plates connect to the insulated terminals on the capacitor and the rotor is grounded to the capacitor frame.

As the shaft is turned counterclockwise, the plates mesh. This increases the total surface area between the two sets of plates and increases the total capacity.

When handling the capacitor, care must be taken to keep from bending the plates. The capacitor is shorted if any adjacent plates touch each other. Similarly, all four terminals on the capacitor are connected to the stator. Thus, if any of the terminals is shorted to the frame, the capacitor is shorted.

As you will see in the following experiments, the tuning capacitor will be connected into the resonant circuit of an rf oscillator. You will be able to change the total capacity in the circuit by rotating the shaft of the tuning capacitor. Therefore, the tuning capacitor will vary the frequency of the oscillator output signal.

Trimmer Capacitor. The trimmer capacitor also has multiple plates. It is called a compression type since the capacity is adjusted by turning the screw which changes the spacing between the plates. Tightening the screw squeezes the plates closer, thereby increasing the capacity.

RF Transformer. Transformer TR31 is an rf transformer with one tapped winding. The inductances of the two windings are about the same, so either winding can be tuned to the frequency of the rf oscillator by using the trimmer capacitor.

Physically, the rf transformer resembles the oscillator coil you used in the last kit. The rf transformer also has its own mounting hardware and mounts on top of the chassis.

I-F Transformer. As you will learn in the sixth experiment of this kit, the degree of coupling between the primary and secondary windings of an i-f transformer has a marked effect on the frequency response of the transformer, as well as on the rf voltage output. So that you can demonstrate the effects of different degrees of coupling, one coil of the i-f transformer supplied in this kit has been constructed so that it can be moved back and forth along the coil form.

This transformer was designed especially for NRI. If you should damage it in carrying out the experiments, you can get a replacement only from NRI. Do not write to the manufacturer or try to buy one from a parts jobber.

In other respects, the i-f transformer is just like any other standard 456 kHz interstage or output i-f transformer that is tuned by compression trimmers. Although output voltage will be maximum when the frequency is between 425 and 485 kHz, there will be a certain amount of output throughout the range from approximately 390 kHz with the trimmers tight to nearly 600 kHz with the trimmers at minimum capacity.

Output Transformer. The audio output transformer is used to couple and match the output of an amplifier to a loudspeaker. The transformer matches the high impedance of the amplifier, which is frequently several thousand ohms, to the four-to-eight ohms impedance of a loudspeaker. Be careful not to pull on any of the transformer leads; you might rip the paper wrapped around the coil windings and pull the leads loose from the windings.

Loudspeaker. The loudspeaker which you received is a PM or permanent magnet type. It is typical of those used in table model radio and TV receivers. The audio frequency signal is applied to the terminals, which connect to the voice coil. Signal current through the speaker causes the speaker to reproduce the signal.

Circuit Boards. Two printed circuit boards are included in this kit. These boards are labeled EC26. The boards are laid out in a pattern of squares which are numbered as shown in Fig. 3. The squares are located by a number and letter. For example, square 5H is at the intersection of the fifth column and row H.

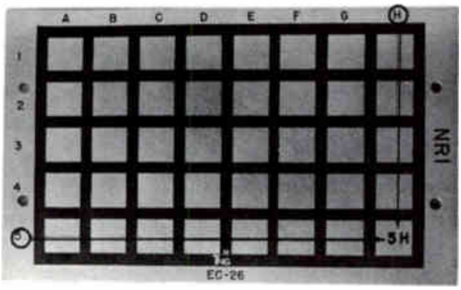


Fig. 3. Circuit board EC26.

When soldering leads to the squares on these boards, use the following technique: Melt a small pool of solder on the foil. Place the leads on top of the solder and heat until the lead penetrates the solder to the foil.

Preliminary Construction

In this section, you will prepare the experimental chassis for the following experiments. You will modify your low voltage power supply, build an audio oscillator, and build part of an audio frequency amplifier. First, you will mount the parts on the chassis. You will then wire and test your circuits.

MOUNTING THE PARTS

Gather the following parts:

2	**Circuit boards (EC26)**
1	**2-lug terminal strip**
1	**Audio output transformer**
3	**Potentiometer mounting brackets**
1	**1k-ohm potentiometer**
1	**3-position rotary switch**
2	**3/8" X 8-32 screws**
2	**8-32 hex nuts**
5	**3/8" X 4-40 screws**
8	**4-40 hex nuts**

Fig. 4 shows the parts mounted on top of the chassis. Refer to this figure as you perform the following steps.

Remove circuit board EC25 and the

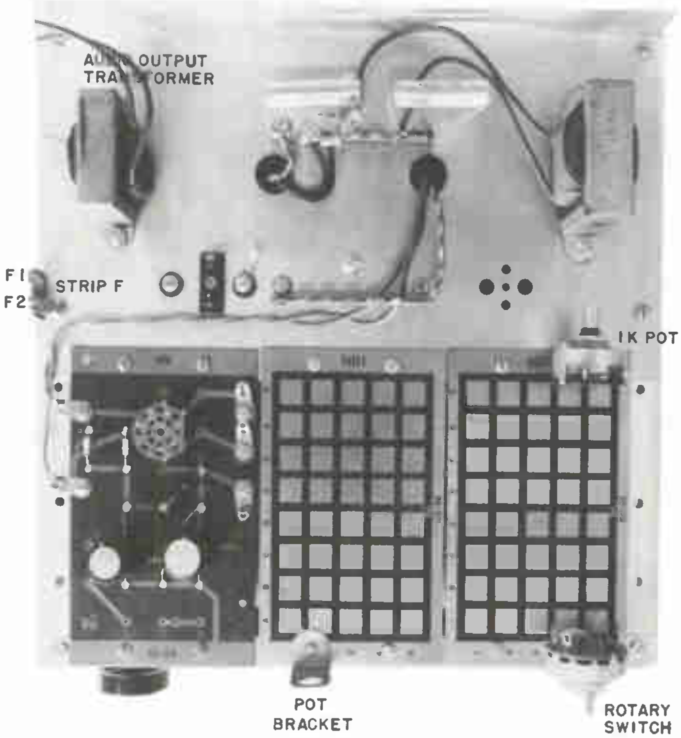


Fig. 4. Refer to this diagram as you install the parts on the chassis.

solder lug from the experimental chassis. Lay the circuit board aside, but keep the 4-40 screws and nuts handy.

Prepare a new circuit board, EC26, for mounting as follows: Secure potentiometer mounting brackets (BR1) to the board at the holes near squares 4A and 4H, using 3/8" X 4-40 screws and nuts. Position the brackets so they are facing away from the circuit board, and tighten the nuts. Place 3/8" X 4-40 screws in the remaining two mounting holes in the board and attach nuts and tighten.

Position the board over the chassis so that the potentiometer mounting brackets are over holes V and AH. (The numbers inscribed along the end of the circuit board should be over the front chassis rail.)

Mount a 1k-ohm potentiometer in the bracket at hole V. Place a lockwasher over the bushing, slip the potentiometer bushing through the hole and attach a control nut. Position the terminals upward and tighten the nut.

Next you will mount the rotary switch in the potentiometer mounting bracket at hole AH. First rotate the shaft of the switch fully clockwise. Slip a knob on the shaft temporarily or use a pair of pliers to grasp the shaft. Slip a control lockwasher over the shaft and bushing of the switch. Slip the bushing through the mounting hole in the bracket and rotate the switch so that the flat on the shaft is downward, pointing toward the circuit board.

Attach a nut and tighten.

Mount another circuit board, EC26, on the chassis at holes AE, AF, S, and T. Turn the board so that the numbers are over the front edge of the chassis rail. Secure with three 1/4" X 4-40 screws through holes AF, S, and T. Attach nuts and tighten.

Attach a potentiometer mounting bracket at hole AE, using a 3/8" X 4-40 screw and nut.

Install the audio output transformer on top of the chassis at holes A and B. Position the transformer so that the blue and red leads are toward the right and secure with 8-32 screws, lockwashers, and nuts. Position these leads so they will not touch any of the circuitry, as you will not use the transformer immediately.

Mount a two-lug terminal strip (strip F) at hole P. Secure the strip using the hardware in hole P. Position the strip as shown in Fig. 4 and tighten the screw.

One of the thin secondary leads of the audio output transformer is tinned with solder throughout its length. Solder this lead to terminal F2. Solder the enamel-covered secondary lead of the transformer to terminal F1.

WIRING THE CIRCUITS

You are now ready to construct the circuits for Experiment 51. The circuits will be constructed on the boards you just installed on your chassis.

Low Voltage Power Supply. You will convert your low voltage power supply on EC24 into a bridge rectifier circuit, using an L-C filter which will supply about +12V to your experimental circuits. You will need the following:

2 LV silicon diodes (SR12)

The schematic diagram of the power supply is shown in Fig. 5. Unsolder and disconnect the green/yellow lead of the power transformer from terminal B7. Push the lead aside and tape it to be sure it does not make contact with the chassis, terminals or other leads.

Solder the cathode lead of a silicon diode to lug 1 of circuit board EC24. Solder the cathode lead of the other

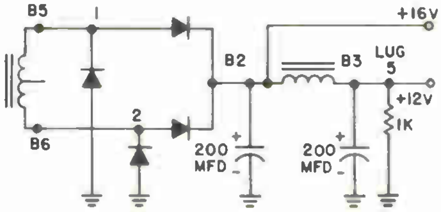


Fig. 5. The low voltage power supply circuit.

diode to lug 2 of EC24. Solder the free (anode) lead of each diode to the ground foil near the end of the circuit board.

Unsolder and disconnect the leads of the filter choke from terminals A4 and A6. Unsolder and disconnect one lead of the 100-ohm resistor from circuit board EC24. Connect the filter choke in place of the 100-ohm resistor as follows. Connect the choke leads to terminals B2 and B3. Connect a length of hookup wire from terminal B2 to the foil connecting the diodes to the input filter capacitor of the power supply circuit. Connect another length of hookup wire from terminal B3 to the foil which connects to lug 5 of EC24.

Your +12V output terminal will be lug 5 of circuit board EC24.

Audio Frequency Oscillator. You will construct a three-frequency phase-shift oscillator circuit on the circuit board on the right side of your chassis. This is the board with the switch and potentiometer attached to it.

The circuit is shown in the schematic diagram in Fig. 6. As you can see, three separate phase shift networks are used

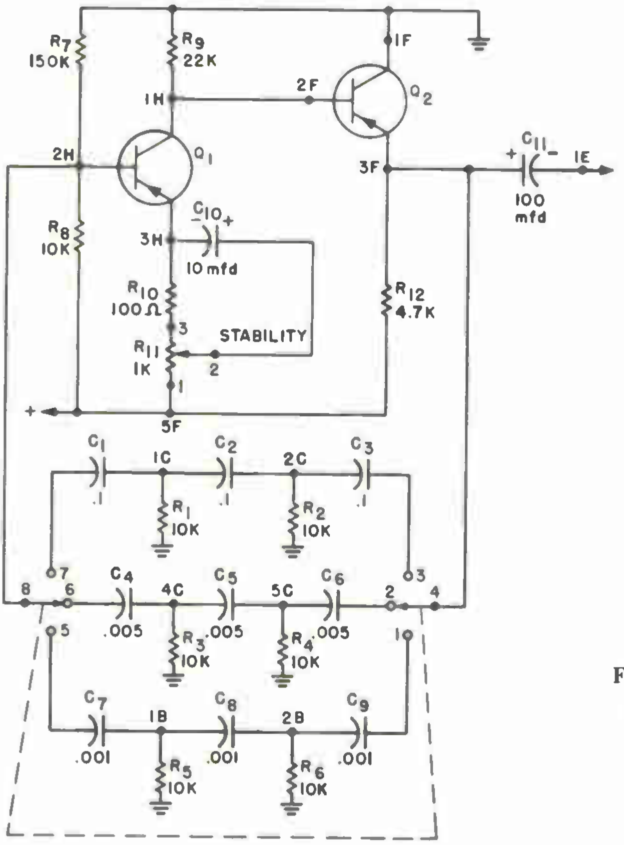


Fig. 6. Schematic diagram of the audio oscillator circuit.

and you select the desired frequency by switching in the appropriate feedback network. Capacitors C_1, C_2 and C_3 and resistors R_1 and R_2 are used in switch position 1 to produce 100 Hz. In position 2, C_4, C_5, C_6, R_3 and R_4 are used for 1 kHz. When the switch is in position 3, the R-C network made up of C_7, C_8, C_9, R_5 and R_6 is used and the oscillator frequency is 10 kHz.

To wire the oscillator circuit, you will need the following parts:

1 100-ohm resistor
1 4.7k-ohm resistor
7 10k-ohm resistors
1 22k-ohm resistor
1 150k-ohm resistor
3 .001-mfd disc capacitors
3 .005-mfd disc capacitors
3 .1-mfd disc capacitors
1 10-mfd electrolytic capacitor
1 100-mfd electrolytic capacitor
2 PNP transistors (TS22), 2N5138
1 Pointer knob

All wiring except for the connections to the 1k-ohm potentiometer will be permanent. Therefore, you will cut off the excess lead lengths as you solder the parts in the circuit.

The connections will be made by soldering the component leads to the squares of copper foil on the circuit board. In each case, you will have two or more leads soldered to a square. To avoid having one lead pull loose while you solder the next, do not leave the soldering iron on the connections too long. You may find it worthwhile to solder each lead to a different corner of the square. Cut the leads and bend them so they will stay in place even if the solder is melted.

You will build the oscillator in two parts. First you will wire the R-C phase shift network. Then you will construct the transistor amplifier section.

Begin by soldering the 10k-ohm resistors to the board near the rotary switch. Shorten one lead of six 10k-ohm resistors to 1/2-inch and bend the short lead downward slightly. Lay a resistor on the circuit board with the short lead on square 4C, as shown in Fig. 7A. Solder the lead to square 4C. Bend the free lead of the resistor so it is touching the ground foil at the end of the board. Solder the

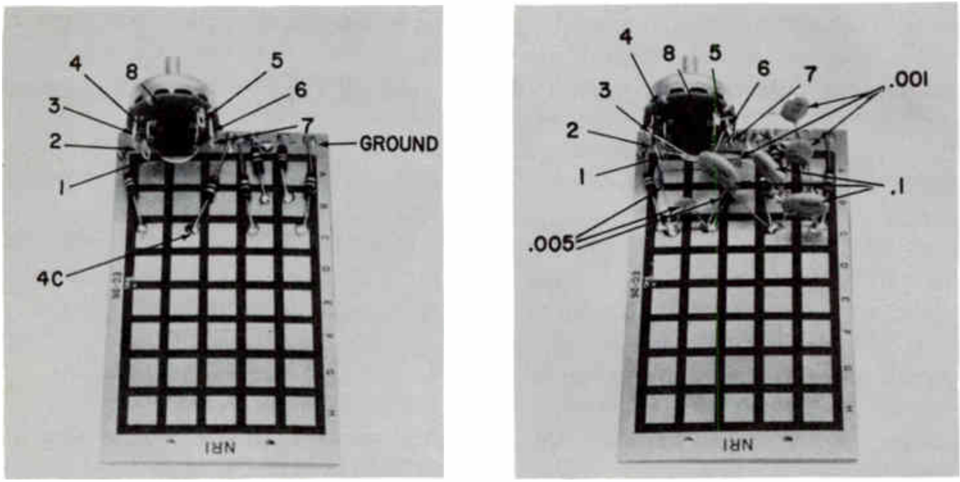


Fig. 7. (A) Mounting the resistors; (B) mounting the capacitors in the oscillator phase-shift network.

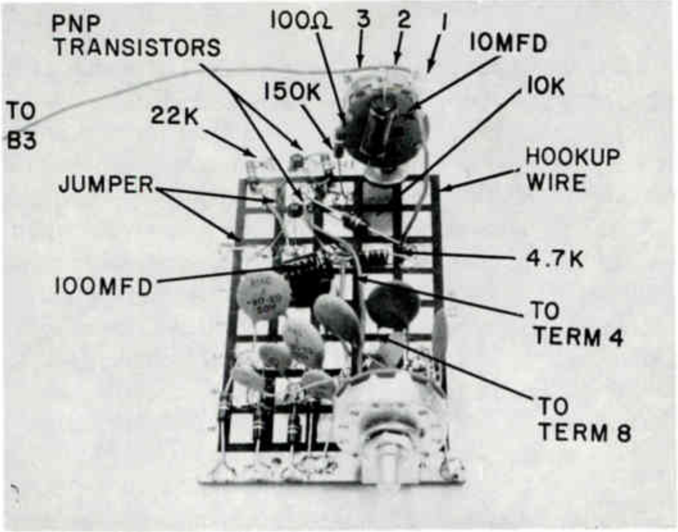


Fig. 7C. The complete audio frequency oscillator.

free lead to the foil and cut off the excess lead length.

In a similar manner, solder the short lead of another 10k-ohm resistor to square 5C, bend the leads so the free lead touches the ground foil and solder it at the end of the board.

Use the same procedure to install and solder the four remaining 10k-ohm resistors between squares 1C, 2C, 1B and 2B and the ground foil at the end of the board.

Now install the nine disc capacitors at the same end of the circuit board. When making connections to the switch, push each lead about 1/16 to 1/8-inch through the hole of the switch terminal and solder. The switch terminals are numbered in Figs. 7A and 7B.

Proceed as follows: Shorten both leads of two .001-mfd capacitors to 1 inch. Refer to Fig. 7B. Solder one lead of a .001-mfd capacitor to terminal 5 of the switch. Bend the leads so the free lead touches square 1B and solder. Solder another .001-mfd capacitor to terminal 1, bend the leads as necessary and solder the free lead to square 2B. Shorten the leads of the remaining .001-mfd capacitor to 1/2-inch and solder this capacitor between squares 1B and 2B.

Shorten the leads of two .1-mfd capacitors to 1 inch. Solder one capacitor between terminal 7 and square 1C. Solder the other .1-mfd capacitor between terminal 3 and square 2C. Shorten the leads of the third .1-mfd capacitor to 1/2-inch and solder it between squares 1C and 2C.

Shorten the leads of two .005-mfd capacitors to 3/4". Solder one capacitor between terminal 6 of the switch and square 4C. Solder the other capacitor between terminal 2 and square 5C. Shorten the leads of the remaining .005-mfd capacitor to 1/2-inch and solder it between squares 4C and 5C.

Take a break and check over your work. You should have six 10k-ohm resistors, three .001-mfd capacitors, three .005-mfd capacitors and three .1-mfd capacitors installed on your circuit board. All leads should be soldered. You will next wire the transistor amplifier section.

Refer to Fig. 7C as you perform the

following steps. Shorten the leads of a 22k-ohm resistor and a 150k-ohm resistor to 3/8-inch and bend the leads of each resistor downward at right angles. Solder the 22k-ohm resistor between square 1H and the ground foil at the end of the board. Similarly, solder the 150k-ohm resistor between square 2H and the ground foil.

Shorten the leads of a 100-ohm resistor to 1/2-inch and solder the resistor from square 3H to terminal 3 of the 1k-ohm potentiometer. Shorten the leads of a 10k-ohm resistor to 3/4-inch and solder the resistor between squares 2H and 5F.

Shorten the leads of a 4.7k-ohm resistor to 1/2-inch. Solder the resistor between squares 3F and 5F.

Shorten the leads of a 10-mfd electrolytic capacitor to 3/4-inch. Solder the positive lead to terminal 2 (the center terminal) of the 1k-ohm potentiometer. Solder the negative lead of the capacitor to square 3H.

Solder a short length of wire between terminal 1 of the 1k-ohm potentiometer and square 5F.

Solder a short length of hookup wire between squares 1H and 2F. Solder a short length of bare wire from square 1F to the ground foil at the edge of the board.

Shorten the leads of a 100-mfd electrolytic capacitor to 1/2-inch. Solder the positive lead to square 3F and solder the negative lead to square 1E.

Connect and solder a length of hookup wire from terminal 4 of the switch to square 3F. Connect and solder another length of hookup wire from terminal 8 of the switch to square 2H.

Identify the leads on the two PNP transistors (2N5138), by referring to Fig. 2A. Spread the leads of one transistor and mount it on the board. Solder the collector, base and emitter leads to squares 1H, 2H and 3H, respectively. Be careful to keep the other leads from coming loose.

In a similar manner, solder the collector, base and emitter leads of the other PNP transistor to squares 1F, 2F and 3F, respectively.

Inspect the board for short circuits and wiring errors. You can check it against Figs. 6 and 7. Also, test each solder connection by pulling each wire gently.

Finally, solder a length of hookup wire between terminal 1 of the 1k-ohm potentiometer and terminal B3 on the chassis.

Install a pointer knob on the switch shaft. Loosen the setscrew in the knob with a small screwdriver, slip the knob on the shaft and tighten the screw against the flat on the shaft.

When you complete the work, test the oscillator. Rotate the 1k-ohm stability control potentiometer fully counterclockwise and energize your circuit. Connect your tvom to measure the ac voltage between the chassis and square 1E. Adjust the 1k-ohm stability control for a reading. You should read 1.5V ac or more. Try all three switch positions and readjust the stability control slightly, as necessary. The ac output voltage at 1E should be approximately the same on all three frequencies.

If your oscillator does not work, check your wiring carefully and trace out each connection. Measure the dc bias voltage on both transistors. You should measure about –.6V between the emitter and base of each transistor. If the voltages are incorrect, look for an open in the ground or collector circuit or for trouble in the positive supply voltage. If you have trouble which you cannot locate, write for help before you attempt to perform the experiments.

WIRING THE AUDIO AMPLIFIER

You will now wire the audio amplifier circuit shown on the schematic in Fig. 8.

You will need the following:

- 1 47-ohm resistor
- 1 100-ohm resistor
- 1 10K-ohm resistor
- 1 6-mfd electrolytic capacitor
- 1 100-mfd electrolytic capacitor
- 1 NPN transistor (TS21), 2N5134

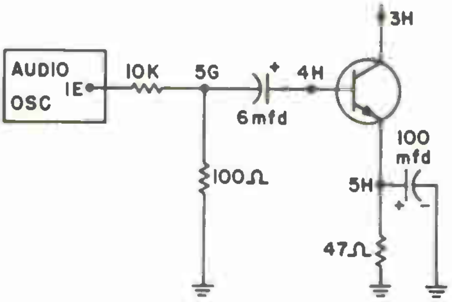


Fig. 8. The voltage divider and amplifier wiring.

The amplifier and voltage divider circuit will be assembled mainly on the center circuit board, which we will call the "experimental circuit board".

To wire the voltage divider, solder a 10k-ohm resistor between square 1E of the oscillator circuit board and square 5G of the experimental circuit board. Solder a 100-ohm resistor between square 5G of the experimental board and the ground foil at the outer edge of the board.

Solder a 6-mfd electrolytic capacitor between squares 4H and 5G of the experimental board, with the positive lead to 4H.

Solder a 47-ohm resistor and a 100-mfd capacitor in parallel between square 5H and the ground foil of the experimental board. The positive lead of the capacitor goes to square 5H.

Solder an NPN transistor to the experimental board. Be sure you can identify the leads and solder the emitter, base and collector leads to squares 5H, 4H and 3H, respectively.

As shown in Fig. 8, your amplifier is not complete. You will add parts in performing the following experiment.

EXPERIMENT 51

Purpose: To show how a loudspeaker converts electrical signals into sound and to show how a loudspeaker can be coupled to an audio amplifier.

Introductory Discussion: In this experiment, you will learn something about how the loudspeaker is constructed and how it works. You will then connect the loudspeaker to an audio amplifier and use it to reproduce a signal. You will also experiment with various methods of driving the loudspeaker. For Steps 2, 3, and 4 you will use your audio frequency oscillator as a signal source and you will use a single stage amplifier to drive the speaker. The amplifier consists of an NPN transistor. Initially, it will be operated in the common emitter mode, with the signal applied to the base and taken from the collector.

Experimental Procedure: For this experiment, you will need the experimental chassis with the oscillator and amplifier circuits wired, your tvom and the following:

- 1 Loudspeaker
- 1 1k-ohm resistor
- 1 3.3k-ohm resistor
- 1 4.7k-ohm resistor
- 1 10k-ohm resistor
- 1 150k-ohm resistor
- 1 6-mfd electrolytic capacitor
- 1 Test clip

Step 1: To demonstrate how the permanent magnet loudspeaker works.

Place the loudspeaker on your work surface so that you can reach its terminals. Set your tvom to measure resistance on the R X 1 range, and measure the resistance between the terminals of the loudspeaker. You should read quite a low resistance, probably less than 3 ohms.

Note that as you make the connection to the terminals, you hear a cracking noise in the loudspeaker. This is due to a sudden change in current passing through the coil and it causes the cone of the speaker to move. Touch the speaker cone with your fingers while you make and break the ohmmeter connection to the speaker terminals. You should feel the cone move slightly as the connection is opened. Move the polarity switch on the tvom to reverse and repeat the test. This time the cone of the speaker should move in the opposite direction.

Prepare two lengths of hookup wire about 12 inches long. Connect them between the speaker terminals and terminals 1 and 2 of strip F, the two-lug terminal strip near the audio output transformer.

Slip the test clip on the tvom probe. Switch the tvom to read ac voltage on the 1.2V range and clip the ground lead and probe to the blue and red leads of the audio output transformer. This will leave both hands free. Move the cone of the loudspeaker in and out rapidly with your fingers while observing the meter. You should see an indication on the meter.

Place the speaker near the speaker of a radio or whistle into it and observe that the tvom indicates an ac voltage.

Discussion: As you can see, the loudspeaker is made of a paper cone, a voice coil and a permanent magnet which are held together by a metal frame. The voice coil is physically attached to, and drives the cone. The permanent magnet is placed behind the voice coil. A pole piece conducts the magnetic field to the voice coil.

The voice coil is energized by a signal applied to the loudspeaker terminals. Current passes through the voice coil and sets up a magnetic field. This field interacts with the field of the permanent magnet. When current passes in one direction, the voice coil and the permanent magnet attract each other. Thus, the voice coil and the cone move in one direction. When the current is reversed, the two fields repel each other and the cone moves in the opposite direction. The frequency and strength of the signal current control the rate and the distance that the cone moves.

The voice coil in your speaker has a nominal impedance of 3 to 4 ohms. This was confirmed by your dc resistance measurement. When you connected your ohmmeter across the voice coil a current of about 100 ma flowed and caused the voice coil to move, producing the sound in the speaker. The current, produced by the 1.5-volt cell in the ohmmeter, was limited by the 10-ohm resistor in the ohmmeter circuit and the impedance of the speaker. The click in the loudspeaker was due to the sudden change in current.

You were able to reverse the direction of current through the voice coil simply by moving the polarity switch on the tvom. As you know, the polarity switch reverses the connections to the probe and ground lead.

In the latter part of this step, you found that the speaker can act as an ac generator. By moving the cone, you caused the voice coil to move within the field of the permanent magnet. The winding of the voice coil cut the magnetic lines of force and a voltage was generated in the coil. With suitable coupling, a loudspeaker can be used as a microphone to convert sound waves into an electrical signal.

Step 2: To show the loudspeaker transformer-coupled to the output of an audio amplifier.

You will use the circuit shown in the schematic in Fig. 51-1. Solder the red lead of the audio output transformer to lug 5 of EC24 and solder the blue lead to square 3H on your circuit board. Solder a 150k-ohm resistor between square 4H and lug 5 of EC24. Solder a 10k-ohm resistor between square 4H and the outer ground foil on the circuit board.

Set the frequency selector switch on your oscillator to position 2, turn the power on and listen for a tone in the loudspeaker. The tone, which is produced by a phase-shift oscillator, has a frequency of about 1000 Hz. This is one of the standard audio test frequencies.

Set your tvom to measure ac voltage on the 12-volt range and measure the voltage across the primary winding of the audio output transformer. Clip the ground lead to the chassis and touch the probe to the blue transformer lead. Read the ac voltage and record the value in the space provided on the first line on the chart in Fig. 51-2.

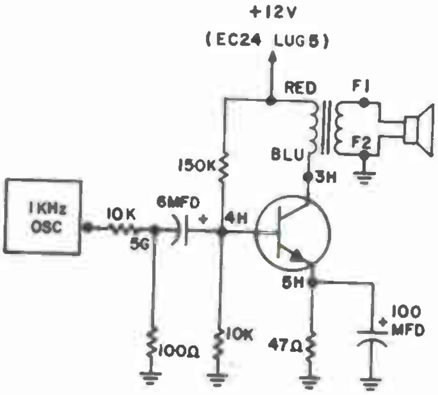


Fig. 51-1. The circuit used for Step 2.

STEP NO.	MEASUREMENT	VALUE
2	Voltage across primary	2V
	Current in primary	.4 ma
	Voltage across speaker	—
3	Voltage across speaker	—
	Voltage at collector	—

Fig. 51-2. Use this chart for recording data in Steps 2, 3 and 4.

Next find the signal current through the collector and the transformer primary circuit. You can assume that the impedance of the transformer winding is 5000 ohms. Thus, you can use the Ohm's Law formula, I = E/Z, where Z is the primary impedance value of 5000 ohms. Compute the current and record it in the space provided in Fig. 51-2.

Now measure and record the voltage across the speaker terminals. The voltage may be too low to measure. If so, place a dash (–) in the space provided in the chart. Turn the circuit off.

Step 3: To show the speaker shunt-connected to the amplifier. Next, you will use the circuit shown in the schematic in Fig. 51-3.

.0004
5000)2.0000
2.0000

.4 ma.

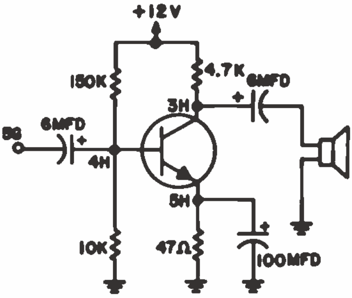


Fig. 51-3. The loudspeaker connected in shunt with the amplifier.

Unsolder and disconnect the blue and red audio output transformer leads. Connect a 4.7k-ohm resistor between square 3H and lug 5 of EC24. Solder the positive lead of a 6-mfd electrolytic capacitor to square 3H. Unsolder the speaker lead from terminal F1 and solder it to the free lead of the 6-mfd capacitor. Check your wiring carefully against the schematic.

Turn the circuit on and note the level of the sound from the speaker. Measure the ac voltage across the speaker terminals. The voltage should be less than .1V. Record the value in Fig. 51-2. Move the probe to the collector side of the 6-mfd coupling capacitor at square 3H and note that the voltage is low there also. Unsolder the speaker lead from the capacitor and note the large increase in the ac voltage at the collector of the transistor. Record the value in the chart. The increase in voltage indicates that the speaker was severely loading the transistor amplifier.

Step 4: To show that power amplification is necessary to drive the speaker.

Construct the power amplifier circuit shown in Fig. 51-4. Connect a length of hookup wire from the collector terminal (the solder lug) of the power transistor mounted at hole C to a ground terminal. Connect a 3.3k-ohm resistor between the base and emitter terminals of the transistor. The emitter terminal is nearest to circuit board EC24. Solder the free speaker lead to the emitter terminal. Replace the 4.7k-ohm resistor with a 1k-ohm resistor. Disconnect the capacitor lead from square 3H. Solder the positive lead of the 6-mfd capacitor to the base terminal of the power transistor and solder the negative lead of the capacitor to square 3H. Unsolder the other speaker lead from terminal F2 and connect it to terminal B2.

Check your wiring very carefully against the schematic diagram and be sure all connections are soldered.

Energize the circuit and note that the volume has increased significantly. Now measure the ac voltage between ground and the collector of transistor Q_1 at square 3H. Record the value in Fig. 51-5. Similarly, measure and record the ac voltages between ground and the base of Q_2 and across the speaker terminals.

Turn the equipment off.

Discussion: Typically, a loudspeaker is

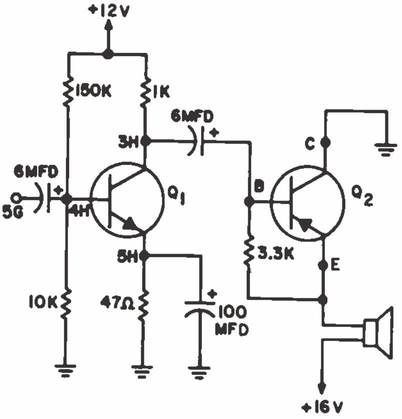


Fig. 51-4. Two-stage amplifier using the power transistor.

VOLTAGE MEASUREMENT	VALUE
Q_1 Collector	—
Q_2 Base	1.3V
Across speaker	—

Fig. 51-5. Use this chart for Step 4.

a low impedance current-operated device. Therefore, a stepdown transformer is frequently used with a speaker operated from a high impedance source, as was the case in Step 2. The amplifier output impedance was several thousand ohms and the speaker impedance was about 4 ohms. The transformer has a step-down ratio (turns-ratio) of approximately 40 to 1. The impedance ratio of a transformer is the square of the turns-ratio, or about 1,600 to 1 for the transformer you are using. Thus the transformer can match the low impedance speaker to the high impedance amplifier circuit.

You should be able to see the transformer action from the data for Step 2 in Fig. 51-2. The ac voltage across the speaker was much less than the voltage across the primary of the transformer. You should have found that the signal current in the primary was quite low, on the order of .5 to .6 ma. Because the transformer steps up the current in the same proportion as it steps down the voltage, the speaker current was about 40 X .6 ma or about 24 ma.

The speaker loaded the amplifier badly in Step 3. The coupling capacitor acted as a short circuit at the signal frequency and the speaker impedance is quite low. Thus, the transistor had approximately 4 ohms shunted across it. The amplification of the transistor was held to a minimum and little output was obtained. As you saw, when the speaker was disconnected, the ac voltage at the collector increased sharply.

In Step 4, you used the power transistor as a power amplifier stage. The transistor was connected as an emitter follower, with the speaker as the emitter load. You should have noticed the increase in sound volume and the increase in the values of ac voltages at each of the three test points listed in Fig. 51-5.

The power amplifier presented a relatively light load to transistor Q_1, while acting as a low impedance source for the speaker. You will note that the signal voltage at the emitter of the power transistor was lower than the signal voltage at the base. Thus, the stage provided an increase in the signal current, with no signal voltage gain. There are cases, however, where a power amplifier provides voltage amplification as well.

Instructions for Statement 51: For this Statement, you will connect the speaker into the collector circuit of transistor Q_2 through the audio output transformer. You will then take measurements and determine whether or not the output stage is amplifying the signal voltage.

Use the circuit shown in Fig. 51-6.

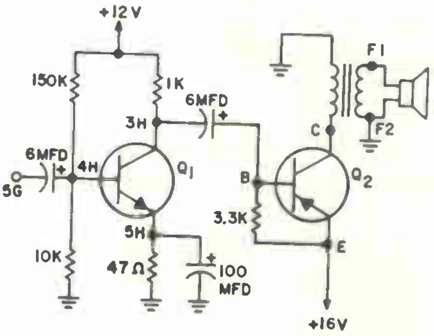


Fig. 51-6. The circuit for Statement 51.

Disconnect the speaker leads from the emitter terminal of the power transistor and terminal B2. Solder a length of hookup wire between these two points. Solder one speaker lead to terminal 1, and solder the other speaker lead to terminal 2 of strip F. Unsolder and disconnect the length of hookup wire between the collector terminal and the power transistor and ground. Solder the blue lead of the audio output transformer to the collector terminal and solder the red lead of the transformer to a ground terminal. Check your work against the schematic.

Energize the circuit and listen to the sound to be sure the circuit is working. Measure the ac voltage across the primary winding of the audio output transformer. Jot down the readings in the margin and answer the Statement.

,34V

Statement No. 51: When I measured the ac voltage at the collector and base of transistor Q_2, I found that the ac voltage at the collector was:

(1) less than
(2) equal to
[✓ *(3) greater than*]

the ac voltage at the base. Therefore, the power transistor provided:

[✓ *(1) voltage gain.*]
(2) no voltage gain.

EXPERIMENT 52

Purpose: To demonstrate how tone controls work.

Introductory Discussion: Tone controls are provided on an audio amplifier to enable the listener to adjust for the most pleasing sound. This is done by varying the relative amplification which the low, middle and high frequencies receive. As an example, for heavy or strong bass, the low frequencies are amplified more than the middle and high frequencies; for more brilliant sound, the highs are amplified more than the middle and low frequencies.

You will use three audio frequencies to demonstrate how tone controls work. You will apply each frequency to the input of your amplifier separately and observe their relative output levels. Then, you will see how the controls affect the amplifier frequency response.

Experimental Procedure: For this experiment, you will need your chassis, your tvom and the following parts:

1 .01-mfd disc capacitor
1 .1-mfd tubular capacitor
1 .25-mfd tubular capacitor
1 50k-ohm potentiometer (PO100)
1 Pointer knob

Mount a 50k-ohm potentiometer in the potentiometer mounting bracket at hole AE. Place a control lockwasher over the bushing. Position the potentiometer in the bracket so the terminals are upward, attach a control nut and tighten. Install a pointer knob on the shaft of the potentiometer.

You will use the phase-shift oscillator, which is wired on one of your circuit boards, and the two-stage amplifier from the last experiment. The circuit is shown in Fig. 52-1. If you find that the sound is too loud or too weak, you may substitute a 22k or 4.7k-ohm resistor for the 10k-ohm resistor connected to square 5G.

Step 1: To determine the frequency response of the amplifier.

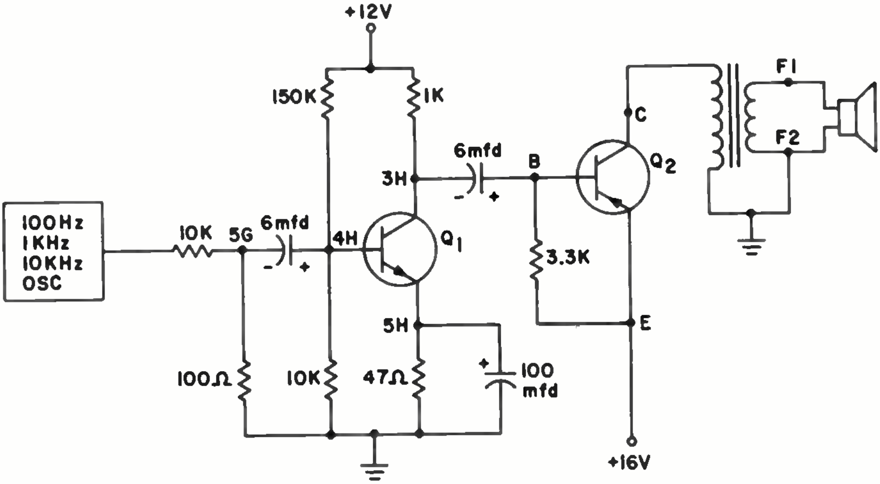


Fig. 52-1. The circuit used in Step 1.

Energize your circuit and set the frequency selector switch on the oscillator circuit board fully counterclockwise to position 1. In this position, your oscillator produces a 100 Hz tone, which should sound like a low rumble in the loudspeaker. Measure the ac voltage between the chassis and square 1E of the oscillator board. This is the oscillator output signal voltage which is applied to the amplifier through the 100:1 voltage divider. Therefore, divide your reading by 100 and record the result as the input signal in Fig. 52-2. Similarly, measure and record the signal voltage at the collector of transistor Q_1 (square 3H), the collector of transistor Q_2 and across the speaker.

Switch the frequency selector to position 2 for a 1 kHz signal. Repeat the four voltage measurements and record your readings in Fig. 52-2.

Switch the oscillator switch to the 10 kHz position (position 3) and take the measurements at this frequency to complete the chart for Step 1, in Fig. 52-2.

Step 2: To show the effect of reducing the value of the capacitor coupling the signal between stages.

Turn off the equipment and disconnect the electrolytic capacitor connected between square 3H and the base terminal

FREQUENCY	INPUT	Q_1 COLLECTOR	Q_2 COLLECTOR	SPEAKER
100 Hz	.02 3 .5	.07	0V	0.1
1000 Hz	.02	.09	12.5	.09
10 kHz	.02	.08	13.5	.12

2,38

Fig. 52-2. The chart for Step 1.

STEP	FREQ.	OUTPUT
2A (.1 MFD)	100 Hz	4.5V
	1000 Hz	12.8V
	10 kHz	13.5V
2B (.01 MFD)	100 Hz	0V
	1000 Hz	8.2
	10 kHz	12.6

[illegible]

Fig. 52-3. Record results of Step 2 here.

of the power transistor and replace it with a .1-mfd tubular capacitor. Connect the tvom across the speaker terminals (terminals F1 and F2) and turn the circuit on.

Turn the frequency selector switch to positions 1, 2 and 3 and measure the output voltages for 100, 1,000 and 10,000 Hz. You should find that the output increases as you switch to higher frequencies. Record your readings in the chart in Fig. 52-3.

Replace the .1-mfd capacitor with a .01-mfd disc capacitor. Repeat the test, measuring the output at each frequency. Record your results in Fig. 52-3 and turn off the equipment.

Step 3: To show the effect of connecting an R-C feedback network between the input and output of the first amplifier stage.

Make the circuit changes shown in Fig. 52-4. Remove the .01-mfd capacitor used in Step 2 and replace it with the 6-mfd electrolytic capacitor you used originally. Now, connect one lead of a .25-mfd tubular capacitor to terminal 2 (the center terminal) of the 50k-ohm potentiometer. Connect the free lead of the capacitor to the collector of transistor Q_1 at square 3H. Prepare about an 8-inch length of hookup wire and connect it to terminal 3 (the right terminal) of the 50k-ohm potentiometer. Solder the other lead to the Q_1 base terminal, square 4H.

Turn the circuit on and measure the output voltage across the speaker terminals at 100 Hz. Rotate the potentiometer

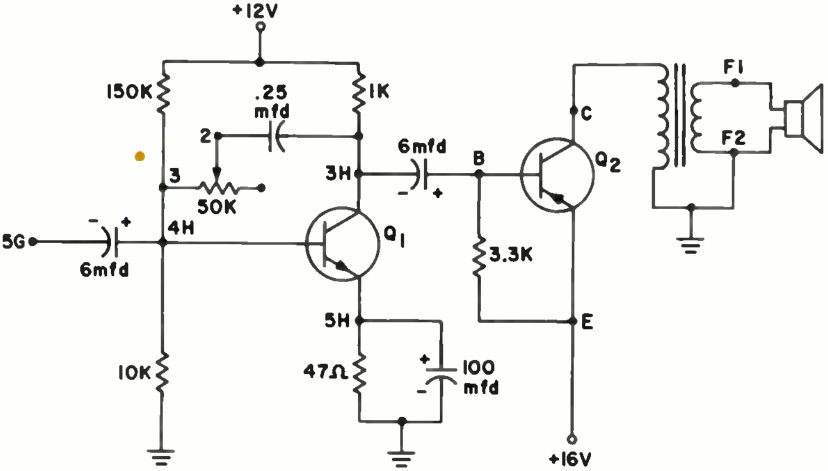


Fig. 52-4. The circuit for Step 3.

STEP	FREQ.	OUTPUT	
		CONTROL CCW	CONTROL CW
3	100 Hz	8.2	9.0
	1000 Hz	6.2	12.5
	10 kHz	7.4	13.5
4	100 Hz	9.2	.9
	1000 Hz	12.7	8.0
	10 kHz	13.6	12.5
5	100 Hz	4.7	5.0
	1000 Hz	5	8
	10 kHz	4.5	7

Q2 Collector

Fig. 52-5. Use this chart for Steps 3, 4 and 5.

throughout its range and notice how the sound level varies. Record both the voltage levels with the potentiometer fully counterclockwise and fully clockwise in the chart in Fig. 52-5. Similarly, measure and record the output for frequencies of 1000 Hz and 10 kHz with the potentiometer fully counterclockwise and fully clockwise.

Step 4: **To show how low-frequency response can be varied by shunting a small coupling capacitor with an R-C network.**

Change your wiring to the circuit shown in Fig. 52-6. Unsolder and remove the .25-mfd capacitor. Remove the 6-mfd coupling capacitor lead from the base terminal of the power transistor and solder it to terminal 2 of the 50k-ohm potentiometer. Solder a .01-mfd capacitor between square 3H and the power transistor base terminal. Connect the series-connected 6-mfd capacitor and 50k-ohm potentiometer across the .01-mfd coupling capacitor. Unsolder the potentiometer lead from square 4H and solder it to the power transistor base terminal.

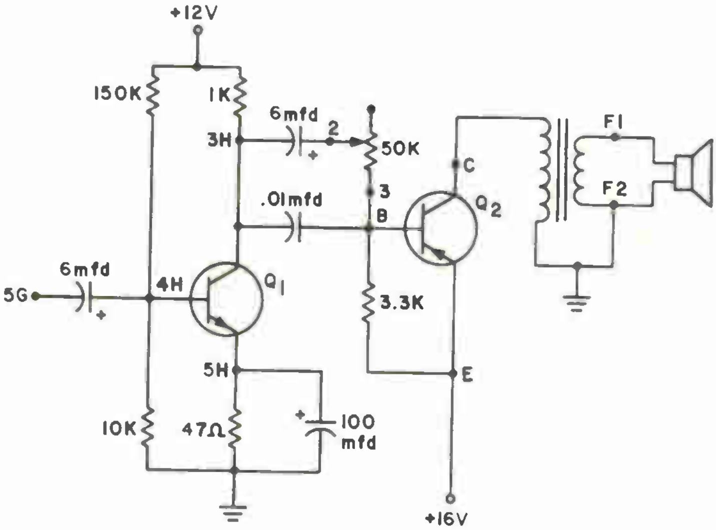


Fig. 52-6. The circuit for Step 4.

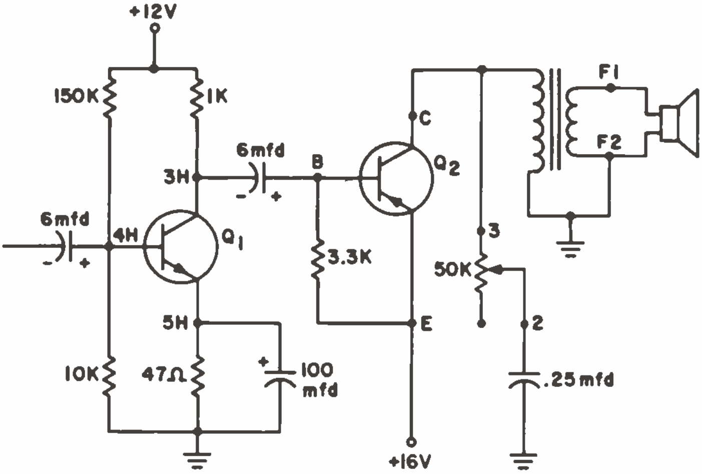


Fig. 52-7. The circuit used for Step 5.

Energize the circuit and vary the potentiometer while listening to each of the three tones. Note that the low tone is affected more than the high when you rotate the potentiometer. Measure the output level for each frequency with the potentiometer fully counterclockwise and fully clockwise, and record the values in the chart in Fig. 52-5.

Step 5: To show the effect of shunting the primary winding of the output transformer with an R-C network.

Change the circuit as shown in Fig. 52-7. Remove the .01-mfd capacitor and reconnect the 6-mfd capacitor between the base of the power transistor and square 3H. Be sure to connect the positive capacitor lead to the power transistor base. Connect the .25-mfd capacitor between terminal 2 of the potentiometer and the ground foil. Unsolder the potentiometer lead from the base terminal of the power transistor and solder it to the collector terminal of the power transistor.

Turn the circuit on and note how the 50k-ohm potentiometer affects the output sound at each of the three frequencies. Record the voltage levels for each frequency in Fig. 52-5 with the potentiometer at each extreme. Turn the equipment off.

Discussion: In this experiment, you measured the signal levels in an audio amplifier and demonstrated several methods of changing the amplifier frequency response. In Step 1, you measured the signal levels at various points in the amplifier to determine the normal amplifier response. You should have found that the three frequencies were amplified nearly equally by each of the amplifier stages. Thus, we can say that the amplifier frequency response is nearly "flat" over the range of 100 to 10,000 Hz.

Capacitance was used in each of the following steps to alter the frequency response of the amplifier. The reactance of a capacitor is inversely proportional to frequency. This can be seen from the formula for capacitive reactance:

$$X_C = \frac{1}{2\pi FC}$$

In Step 2, lower values of coupling capacitor were connected between the two stages. The smaller capacitor passed the high frequencies with less attenuation than the low frequencies. Thus, in the output, the high frequencies were emphasized. In any R-C coupling network, the coupling capacitor and the input resistance of the following stage form a signal voltage divider.

Normally the capacitance value is chosen so that it has negligible reactance at the signal frequency. Therefore, little or no signal voltage is dropped across the coupling capacitor. However, if the capacitance is small and has appreciable reactance at the signal frequency, reduced signal will be available at the input of the following stage. In this step, the capacitors were small enough so that the middle and low frequencies were highly attenuated. However, the 10 kHz signal was passed readily.

Inverse feedback was used in Step 3. The capacitor was used to couple the signal from the collector of Q_1 back to the base. This is degenerative feedback, which is 180° out-of-phase with the input, and it was used to reduce the effective input signal level. The capacitive reactance to the high frequencies was low. Thus, it coupled back more of the high frequency signal voltage. As a result, the overall gain of the stage was highest at the lowest frequency.

The 50k-ohm potentiometer varied the effect of the capacitive feedback. Increasing the resistance decreased the amount of signal coupled through the network at each frequency. Thus it reduced the difference in gain for the various frequencies.

For Step 4, you used an R-C network in parallel with a small coupling capacitor. The small coupling capacitor attenuates middle and low frequencies severely, as you saw in Step 2. The 6-mfd capacitor passed the low frequencies more readily. Therefore, as the resistance of the potentiometer was decreased, the low and middle frequencies were attenuated less and, consequently, received more overall amplification.

An R-C network was connected in

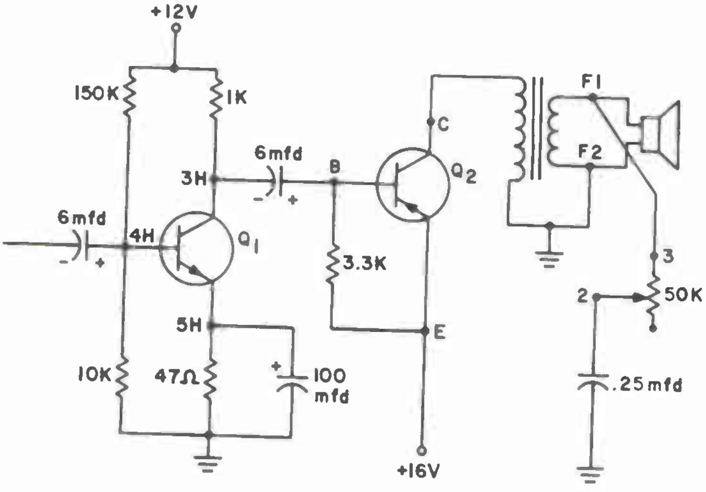


Fig. 52-8. The circuit for Statement 52.

parallel with the output of transistor Q_2 in Step 5. The capacitor filtered out the high frequencies, just as any filter capacitor would do. It has a high reactance to low frequencies. Therefore, the low frequencies were affected very little by the filtering action. The 50k-ohm potentiometer varied the amount of filtering which the capacitor could produce. Thus it varied the attenuation of the high and middle frequencies. As a result, the low frequencies would seem to be emphasized.

In Steps 2 through 5, you saw several methods of altering the amplifier frequency response. All of the methods employ R-C filtering and they either emphasize or attenuate a band of frequencies. As a general rule, 1,000 Hz is taken as the center frequency. Then the lows are frequencies less than 1,000 Hz and the highs are frequencies greater than 1,000 Hz. The effect of tone controls is gradual: The higher or lower the frequency, the more it is affected by the control.

Instructions for Statement 52: For this Report Statement, you will connect the series-connected potentiometer and the .25-mfd capacitor across the speaker terminals and determine the effect. Unsolder the lead of the 50k-ohm potentiometer from the collector terminal of power transistor and solder it to terminal F1. You now have the circuit shown in Fig. 52-8.

Energize the circuit and observe the amplifier output level at each frequency with the potentiometer set at each extreme. Answer the Statement here and on the Report Sheet and turn your equipment off.

Statement No. 52: When I varied the resistance in series with the capacitor across the speaker, I found that:

(1) the low frequencies were most affected.

(2) the middle frequencies were most affected.

[✓ (3)] there was no noticeable effect.

EXPERIMENT 53

Purpose: To show some of the techniques used to control audio volume and to compare their advantages and disadvantages.

Introductory Discussion: The volume control in a radio or television receiver enables the user to vary the audio output level without changing the tone or distorting the output signal. Many different systems are used. The volume control device itself is almost always a potentiometer and it can be connected to vary either the gain of an amplifier stage or the attenuation of the signal. In rare cases the gain of two or more stages is adjusted by the volume control.

In this experiment, you will demonstrate several volume control methods. You will use your audio frequency oscillator set to 1 kHz as a signal source and, by observing the ac output voltage on your tvom and listening to the sound, you will be able to see how the volume control methods affect the sound output.

Experimental Procedure: You will need the experimental chassis with the audio oscillator and amplifier circuits and the 50k-ohm potentiometer, your tvom and the following:

1 3.3k-ohm resistor

You will begin the experiment with the

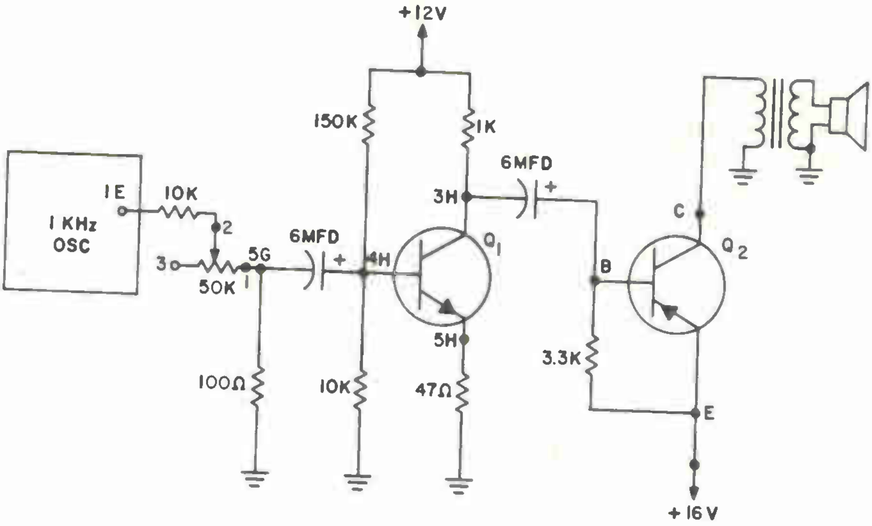


Fig. 53-1. The circuit for Step 1.

circuit shown in the schematic diagram in Fig. 53-1. To prepare for the experiment, unsolder and remove the 100-mfd capacitor from the Q_1 emitter circuit.

Unsolder the .25-mfd capacitor connected to the 50k-ohm potentiometer, and lay it aside; also, disconnect the hookup wire attached to the potentiometer.

Unsolder the 10k-ohm resistor lead from square 5G of the experimental circuit board and connect it to terminal 2 (the center terminal) of the 50k-ohm potentiometer. (You will have to solder a short length of hookup wire to the resistor lead.) Solder a length of hookup wire between terminal 1 (the left terminal) of the 50k-ohm potentiometer and square 5G. Check your wiring against the schematic and be sure all connections are soldered.

Step 1: To show that increasing or decreasing a resistance in series with a signal source will vary the signal amplitude.

Connect your tvom between ground and the collector terminal of the power transistor. Set the meter to read 12 volts ac and turn the circuit on. Set the oscillator for 1 kHz (position 2). Adjust the volume control (the 50k-ohm potentiometer) until maximum signal is indicated on the tvom.

Turn the volume control throughout its range while listening to the sound from the speaker. Also, observe the meter. The volume and the meter indication should vary. Note that the potentiometer cannot completely cut off the sound. Turn off the power.

Step 2: To show that the volume can be controlled by varying the amplifier load impedance.

You will place the potentiometer across the primary winding of the audio output transformer in the collector circuit of the power transistor. Disconnect the potentiometer lead from square 5G. Unsolder the 10k-ohm resistor lead from the center

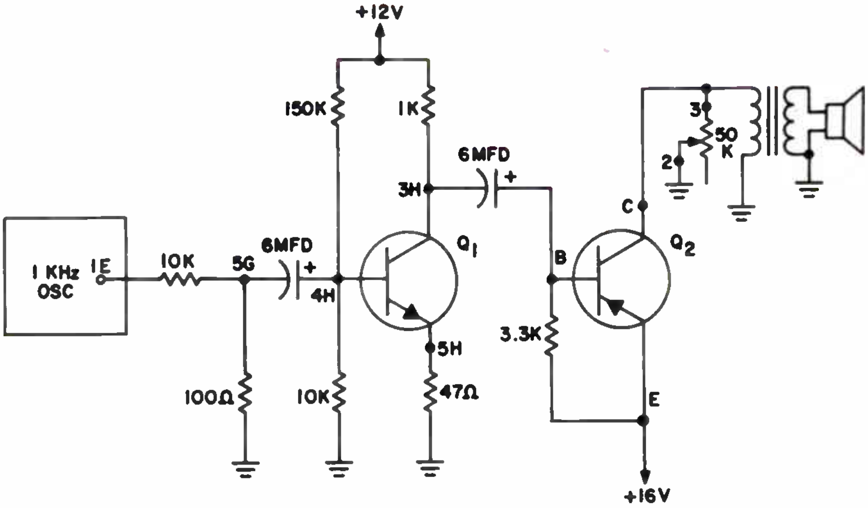


Fig. 53-2. The circuit for Step 2.

terminal of the potentiometer and solder it to square 5G. Now connect terminal 2 of the potentiometer to ground.

Connect a length of hookup wire from terminal 3 of the potentiometer to the collector of the power transistor. You should now have the potentiometer connected as shown in the schematic in Fig. 53-2.

Turn on the power and rotate the volume control. Observe the meter indication while listening to the sound. The output should vary smoothly from one extreme of the volume control setting to the other.

Step 3: To show that volume can be controlled by varying the bias on an amplifier stage.

Disconnect the potentiometer lead

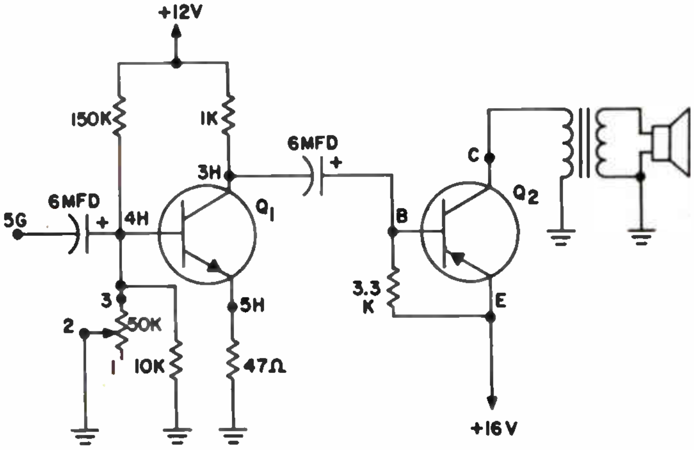


Fig. 53-3. The circuit for Step 3.

from the collector of transistor Q_2 and connect it to square 4H. You now have the circuit shown in Fig. 53-3.

Turn on the power and vary the potentiometer throughout its range while listening to the sound and observing the meter indication. Note that as the resistance is decreased, the volume decreases.

Step 4: To demonstrate a volume control method using a potentiometer as a signal voltage divider.

The circuit for this step is shown in Fig. 53-4. Note that the potentiometer is connected in shunt with the 100-ohm resistor. Wire the circuit as shown. Unsolder the lead of the 6-mfd capacitor from square 5G. Disconnect both potentiometer leads from the circuit. Connect a length of hookup wire from terminal 1 of the potentiometer to square 5G. Solder the lead from terminal 2 of the potentiometer to the free lead of the 6-mfd capacitor. Solder the lead from terminal 3 of the potentiometer to ground. Check over your work.

Turn the equipment on and vary the setting of the volume control while observing the output voltage reading on your tvom and listening for the sound. You should have full output at one extreme and no volume at the other extreme of the volume control rotation. Further, the variation in output level should be smooth. Turn the equipment off.

Discussion: In volume controls, three factors are important: The control should operate smoothly, it should not introduce distortion and the control should dissipate little if any power. The first two factors are fairly obvious. It is annoying to have the volume change suddenly from low to high as the volume control knob is rotated. You expect and prefer that the level be continuously variable from one extreme to the other.

From the preceding experiment, you know that the volume can be varied by varying the level of the high or low tones in the audio frequency output. This is a form of distortion, however. Varying the highs or the lows only would make the reproduction of the speech or music less pleasing.

Most potentiometers used in volume

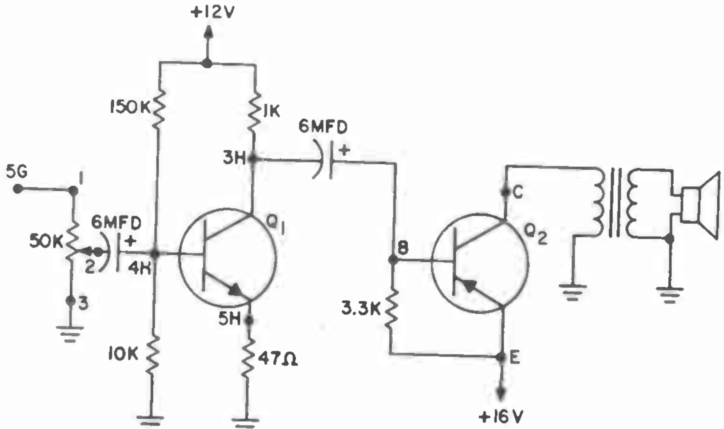


Fig. 53-4. The circuit for Step 4.

control circuits have low wattage ratings. Like fixed resistors, they become overheated and damaged by excessive current. Carbon potentiometers, such as those you have on your experimental chassis, consist of a circular resistive element connected to the end terminals and a sliding contact connected to the center terminal. As the shaft is rotated, the contact slides along the surface of the resistive element. Excessive current will frequently cause the surface of the resistive element to burn where it contacts the slider. This produces intermittent connections and popping or cracking noises in the audio.

Now let us look at the results of the experiment. In Step 1, you connected the potentiometer as a variable resistor between the source and the amplifier circuit. The potentiometer varied the attenuation of the signal applied to the amplifier input stage.

You know from previous experiments that the 10k-ohm resistor and the 100-ohm resistor form a signal voltage divider. By placing the 50k-ohm potentiometer in series with the 10k-ohm resistor, you were able to vary the voltage divider ratio. Consequently the potentiometer made it possible to reduce by approximately 80% the signal voltage applied to the amplifier circuit.

In Step 2, you connected the potentiometer across the primary winding of the audio output transformer. The primary winding and the associated impedances reflected from the secondary and the loudspeaker form the load for this stage.

Changing the resistance parallel with the primary winding altered the impedance and the path of the collector current. With the volume control set for maximum volume, the resistance was high when compared to the impedance of the primary winding. Therefore, most of the current flows through the primary winding and the loudspeaker and produced normal volume.

The volume control was connected so that rotating the shaft counterclockwise reduced the total resistance in shunt with the primary. This reduced the amplifier load resistance, and also reduced the amount of signal coupled into the speaker. At any setting except maximum volume, a heavy current flows through the volume control. Under some circumstances, the current would be great enough to require a higher wattage (and more expensive) potentiometer. Over a long period of time, the current can cause potentiometers of the type you are using to become noisy.

The volume control in this step is able to cut off the sound, or at least reduce it to inaudibility. This is because the minimum resistance of the potentiometer is quite low when compared to the impedance of the primary winding.

In Step 3, you used a volume control arrangement which varied the bias on the first amplifier stage. The potentiometer was connected between the base of the transistor and ground. Note that forward bias on the stage is developed by the voltage drop across the 150k-ohm resistor connected between the positive supply voltage and the base. The potentiometer was connected so that it affected the forward bias.

As the resistance of the potentiometer was reduced, the forward bias on the base of the transistor was lowered. Eventually, a point was reached where the transistor was cut off. Within limits, the gain of the transistor is proportional to the collector current. Thus, with this arrangement you were able to vary the output signal and amplitude.

The primary drawback of this volume

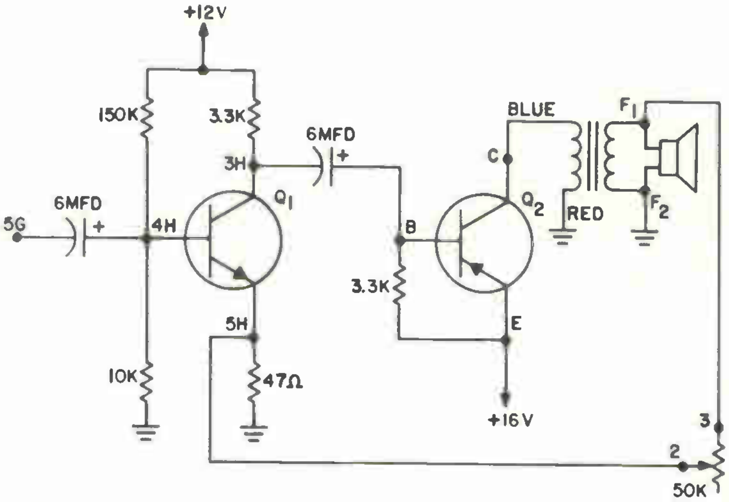


Fig. 53-5. The circuit for Statement 53.

control is the fact that it is prone to produce amplitude distortion. When the control is set for low levels, the bias is very low and negative excursions of the signal can drive the transistor into cutoff. Similarly, high positive peaks would receive more amplification than lower positive peaks. Thus the gain varies with the signal level.

In Step 4 you demonstrated one of the most common volume control circuits. In your circuit, the junction of the 10k-ohm and 100-ohm resistors was for all practical purposes the source of a low level signal. The volume control, then, was across the low level signal source.

For maximum volume, the resistance between the source (square 5G) and the slider on the volume control is at minimum. The full 50,000-ohms is between the slider and ground. As the volume is decreased, the resistance between square 5G and the slider increases while the resistance between the slider and ground decreases. As you already know, the resistance of the transistor input circuit is quite low. Therefore, the signal voltage will be dropped across the portion of the potentiometer between the slider and square 5G.

Further rotation of the potentiometer increases the resistance between the source and the slider and the voltage actually reaching the transistor becomes too low to drive the stage. This, of course, results in no audible output.

Note in Fig. 53-4 that the volume control is connected on the input side of the coupling capacitor. This arrangement prevents the volume control from affecting the bias voltage on the transistor. If the potentiometer were placed so that the slider was connected to the base, the signal reaching the transistor as well as the transistor forward bias would be reduced whenever you turned the volume down. Depending on the level of the input signal, this may produce distortion in the audio, as mentioned earlier.

Instructions for Statement 53: For this Statement, you will connect the potentiometer between the Q_1 emitter circuit and the secondary winding of the audio output transformer and determine the effect of varying the resistance. Change your circuit according to the schematic diagram shown in Fig. 53-5.

Unsolder and remove the length of wire connected between square 5G and terminal 1 of the potentiometer. Unsolder the potentiometer lead connected to ground and solder it to terminal F1. Unsolder the lead of the 6-mfd capacitor from the center potentiometer lead and solder the capacitor lead to square 5G. Solder the free end of the center potentiometer lead to square 5H. Replace the 1k-ohm resistor in the Q_1 collector circuit with a 3.3k-ohm resistor. Check your circuit against the schematic diagram.

Turn your circuit on and vary the setting of the volume control while listening to the sound and observing the output on the tvom. Observe the effect of rotating the volume control in the counterclockwise direction. If your circuit is wired correctly, this will decrease the resistance between the leads of the potentiometer. Make whatever tests are necessary and answer the Statement here and on the Report Sheet.

Statement No. 53: **When I decreased the resistance by rotating the volume control counterclockwise, the overall amplifier gain:**

(1) increased.
[✓ *(2) decreased.*]
(3) remained the same.

EXPERIMENT 54

Purpose: To show how the field effect transistor works and to show that it can be used as an audio frequency amplifier.

Introductory Discussion: The field effect transistor (or FET) is a solid-state device with characteristics very similar to those of a vacuum tube. Some of its characteristics, however, are unique. An understanding of the FET is important to the service technician because FET's are being more widely used in radio and TV receivers. Thus, you will be faced with troubleshooting circuits containing them.

An FET has three terminals called the drain, source, and gate. The schematic symbol shown in Fig. 2B should be familiar to you, as FET's are used in your tvom. A resistive current path or channel exists between the drain and source terminals.

In the FET supplied with this kit, this path consists of a small bar of N-type silicon material. Thus, the device is called an N-channel FET. The gate consists of a piece of P-type material surrounding the N channel. The application of the negative voltage to the gate causes the channel to become less conductive, thus exhibiting a higher resistance.

In this experiment, you will see how the gate voltage affects the current through the channel, you will see how bias voltage is obtained and you will construct and demonstrate a basic amplifier using your FET.

Experimental Procedure: For this experiment, you will need the experimental chassis with the oscillator, power supply and experimental circuit boards, your tvom and the following:

2	1.5V flashlight cells
1	FET (TS20)
1	470-ohm resistor
1	1k-ohm resistor
1	10k-ohm resistor
1	47k-ohm resistor
1	100k-ohm resistor
1	.1-mfd tubular capacitor
1	6-mfd electrolytic capacitor

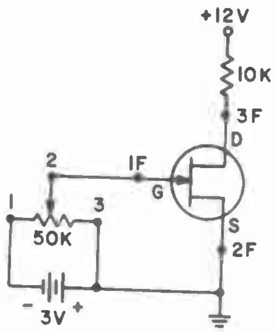


Fig. 54-1. The circuit for Step 1.

You will use the circuit shown in Fig. 54-1. Before wiring the circuit, dismantle the circuit from the previous experiment. Remove the resistors and capacitors connected to squares 3H, 4H and 5H. Leave the signal voltage divider connected to square 5G and ground and leave the transistors in place. Remove the resistor and the emitter lead from the power transistor.

Unsolder and disconnect all 4 leads and remove the audio output transformer.

To wire the battery and potentiometer, prepare two lengths of hookup wire about 8 inches long. Your two flashlight cells should still be connected in series, forming a 3-volt battery. Solder lengths of wire to the positive and negative terminals of the 3-volt battery. Solder the negative battery lead to terminal 1 (the left terminal) of the 50k-ohm bias potentiometer. Solder the positive battery lead to terminal 3 (the right terminal) of the potentiometer. Solder a short length of wire between terminal 3 of the potentiometer and ground (the chassis).

Connect a 10k-ohm resistor between square 3F and lug 5 of circuit board EC24. Connect a short length of hookup wire between ground and square 2F. Connect another length of hookup wire from the center terminal of the 50k-ohm bias potentiometer to square 1F.

Be sure you can identify the leads of the FET. This information is given in Fig. 2B. Then solder the gate, source, and drain leads to squares 1F, 2F and 3F, respectively. Use the same precautions as instructed for handling your other transistors: do not apply excessive heat or physical strain to the leads.

This completes your wiring. Check your work to be sure the circuit is wired according to the schematic diagram.

Step 1: To show that the channel current in an FET can be controlled by applying a negative voltage to the gate.

Turn the circuit on and measure the dc voltage across the 10k-ohm resistor connected between the drain terminal of the FET at square 3F and the positive supply voltage. Vary the 50k-ohm bias control potentiometer and note that the meter reading varies.

Set your tvom to measure negative voltage on the 3-volt range. Move the ground clip to the chassis and measure the voltage between ground and the gate of the FET. Adjust the bias control for 0V. Then switch the tvom to the 12-volt range and move the ground clip to the positive terminal, lug 5 of EC24. Measure the voltage across the 10k-ohm resistor and record it on the first line in Fig. 54-2.

In a similar manner, set the gate voltage to −1V, −2V, and −3V and measure and record the corresponding voltage drops across the 10k-ohm drain resistor.

11.5
12V
12.2
12.2

1.15
1.2
1.22
1.22

When you complete these readings, compute the drain current for each entry. The current in ma is equal to 1/10th the voltage across the 10k-ohm resistor in volts. For example, a voltage of 12V corresponds to 1.2 ma.

GATE VOLTAGE	VOLTAGE ACROSS 10K	DRAIN CURRENT
0	11.5	1.15
−1	[illegible]	1.2
−2	12.2	1.22
−3	12.2	1.22

See Page 32

Fig. 54-2. The chart for Step 1.

Step 2: To show that the source and drain are interchangeable.

Turn the circuit off and unsolder and interchange the resistor lead and the ground lead to squares 2F and 3F.

Connect the tvom across the 10k-ohm resistor, turn the circuit on and vary the potentiometer. Note that the voltage drop across the 10k-ohm resistor varies just as it did in Step 1, although the current now flows through the FET from drain to source.

Step 3: To show another method of biasing an FET.

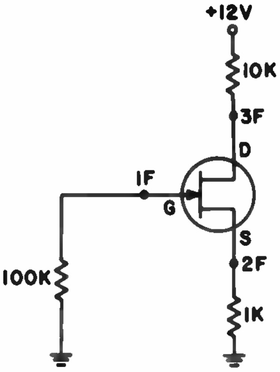


Fig. 54-3. The circuit for Step 3.

You have already used negative fixed bias applied to the gate. Now you will demonstrate self-bias. Turn the circuit off and change it to that shown in the schematic in Fig. 54-3. Disconnect the leads from the battery and the 50k-ohm potentiometer. Unsolder and remove the hookup wire from square 3F. Solder a 100k-ohm resistor between square 1F and the ground foil. Unsolder the 10k-ohm resistor lead from square 2F and solder it to 3F. Solder a 1k-ohm resistor between the ground foil and square 2F. You now have the gate grounded through a 100k-ohm resistor, the 10k-ohm resistor connected in the drain circuit and the 1k-ohm resistor connected between ground and the source.

Turn the circuit on and measure the voltage between ground and the gate terminal at square 1F. You should read zero. Now measure the voltage across the 1k-ohm source resistor. This is the gate bias voltage, as it is equal to the voltage between the gate and source.

0.5

Turn the circuit off and replace the 1k-ohm source resistor with a 47k-ohm resistor. Energize the circuit and determine the bias voltage, as before. Also, measure the voltage across the 10k-ohm resistor and determine the drain current. Jot down the current in the margin.

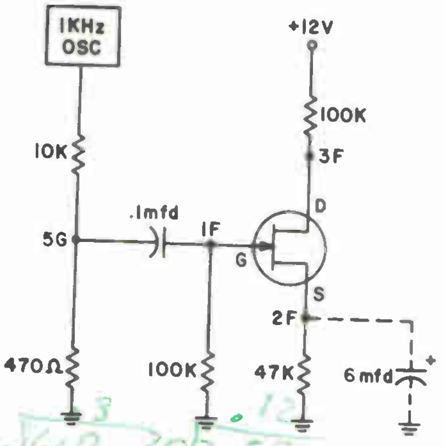
1.0

.02
ma.

Step 4: To show that the FET can be used to amplify ac signals.

Wire the circuit shown in Fig. 54-4. Replace the 10k-ohm drain resistor with a 100k-ohm resistor. Connect a .1 mfd-tubular capacitor between squares 5G and 1F. Replace the 100-ohm resistor connected between square 5G and ground with a 470-ohm resistor. Check your wiring.

(A) Energize the circuit, set the oscil-



.12
20)2.50

.3
20)6.0

Fig. 54-4. Basic amplifier circuit in Step 4.

lator switch to position 2 and measure the ac voltage between ground and square 1E of the oscillator board. This is the oscillator output applied to the voltage divider. The voltage divider has a ratio of about 20 to 1. Thus the signal applied to the FET is about 1/20th of the voltage reading at the oscillator output.

Perform this computation and record the input voltage in the first column of Fig. 54-5. Move the probe of your tvom to square 3F and measure and record the output voltage. Compute the stage gain, using the formula,

$$\text{gain} = \frac{E_{out}}{E_{in}}$$

and record it in Fig. 54-5.

STEP	INPUT	OUTPUT	GAIN
4A	.12V	.12	0
4B	.12V	3.5V	29

Fig. 54-5. The chart for Step 4.

29
.12)3.50
24
110

(B) Solder a 6-mfd capacitor between ground and the source terminal at square 2F. Note that the positive capacitor lead goes to square 2F. Turn the circuit on and measure and again record the output voltage at 3F. The input voltage has not changed. Therefore, you can use the same value as in Step 4A. Compute and record the stage gain for this step. Turn the equipment off.

Discussion: The field effect transistor you used is called a junction FET which is sometimes abbreviated JFET. This means that the gate is in physical and electrical contact with the channel. The P-type gate material must never be made positive with respect to the channel or it will act as a forward-biased diode and will pass excessive current and become damaged.

In Step 1, you recorded the gate input voltage and the resulting drain current. From the data you recorded in Fig. 54-2, you can see that the current was highest when the gate voltage was at zero and the current decreased as you made the gate more negative. This is very similar to what happens to the plate current in a vacuum tube as the grid voltage is varied. In an FET, if you continue to make the gate more negative, you reach a point known as "pinch-off", which corresponds to plate current cutoff in a vacuum tube or collector current cutoff in a bipolar transistor.

The voltage drop across the load resistor in the drain circuit varied with drain current. Therefore, the variation in the voltage at the gate produced larger changes in the voltage across the FET itself.

As stated earlier, the channel in an FET is simply a resistive current path. Thus, like a resistor, it will pass current in either direction. You should have found that the FET acted in exactly the same manner in Step 2 when you interchanged the source and drain connections as in Step 1.

In Step 3, you demonstrated the most common method of biasing an FET. The gate is returned to the negative side of the power supply and a resistor is placed between the negative supply and the source terminal of the transistor. Current flow through the source resistor makes the source positive with respect to ground. The gate, therefore, is negative with respect to the source. This method eliminates the need of a separate bias supply and also makes it possible to use FET's with widely varying internal resistances in an amplifier circuit.

You constructed an amplifier stage in Step 4. This circuit is called a common source amplifier. In Step 4A, the gain was about 2 and the output level was too low to measure accurately. The unbypassed source resistance was responsible for the low gain. Input signal variations caused variations in the source as well as drain current. The voltage drop across the source resistor opposed the signal variations and reduced the effective input signal to an extremely low level.

When you bypassed the source resistor, you found that the gain increased significantly. The bias was held stable so that the input signal variations produced proportional changes in channel current and in the voltage drop across the load resistor.

The signal across the drain resistor is 180° out-of-phase with the input signal; a positive going excursion of the signal increases the source-drain current and produces an increase in the voltage drop across the drain resistor. If the source resistor is left unbypassed, the voltage across it will be in-phase with the applied signal voltage.

Any JFET such as the one you used in this experiment can be handled safely if you heed the same precautions that you do for regular bipolar transistors. Take care not to subject the device to excessive heat, voltage or physical strain.

Another type of FET, called the insulated gate FET, (IGFET, or MOSFET) requires much more care in handling. Although it resembles the JFET, this type of FET has a thin layer of insulation between the gate and channel. This insulation can be broken down by ac voltage pickup on the leads. Therefore, the leads must be kept grounded until the FET is installed in a circuit.

Instructions for Statement 54: For this Report Statement, you will convert your FET stage to a source-follower amplifier, in which the signal is applied to the gate and the output is taken at the source.

Wire the circuit shown in Fig. 54-6. Unsolder and remove the 100k-ohm drain resistor, which is connected between square 3F and lug 5 of EC24. Connect a length of hookup wire in its place. Unsolder and remove the electrolytic capacitor in parallel with the 47k-ohm source resistor. Remove the 470-ohm resistor in the signal voltage divider.

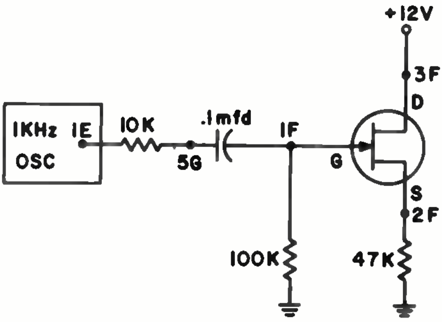


Fig. 54-6. The circuit for Statement 54.

Energize the circuit and measure the input signal voltage at the gate and at the output, which is the source terminal. Turn the equipment off. Compare the two voltage readings and answer the Statement.

Statement No. 54: When I measured the input and output voltages of the FET source follower circuit, I found that the gain was:

2.3 [illegible]

(1) less than .1.
[✓ *(2) between .5 and 1.*]
(3) greater than 5.

[illegible]

EXPERIMENT 55

Purpose: To demonstrate how the stereo indicator on an FM receiver works and to show the effects of common circuit defects in stereo indicator circuits.

Introductory Discussion: Many FM receivers feature an indicator light which glows whenever a stereo transmission is being received. In some receivers, the circuit which operates the light also switches in the stereo detector circuitry. Otherwise, the signal passes through the simpler monophonic circuitry only.

The stereo indicator consists of a sensing circuit in addition to the indicator device. In most sets, the 19 kHz pilot carrier, which is part of the stereo multiplex signal, is monitored. When the pilot carrier is present with sufficient strength, the circuit is actuated. In order to discriminate against other signals, such as audio, a tuned circuit is often placed in the indicator circuit to pass the 19 kHz signal only.

In this experiment, you will use the 10 kHz output of your phase-shift oscillator to represent the 19 kHz pilot carrier. As an indicator, you will use an incandescent pilot lamp. This lamp requires 2V at 60 ma for full brilliance. Therefore, you will operate the lamp from the +16V supply at the input to the L-C filter in the power supply.

Experimental Procedure: For this experiment, you will need the experimental chassis, your tvom, and the following:

1 PNP transistor (TS22)
1 No. 49 pilot lamp
1 Lamp socket
1 1-megohm resistor
1 6.8k-ohm resistor
1 4.7k-ohm resistor
1 220-ohm resistor
1 150-ohm resistor
1 250 pf mica capacitor
1 Signal diode (CR10)

You will begin the experiment with the circuit shown in the schematic diagram in Fig. 55-1. First, disassemble the circuitry on the center circuit board. Leave the

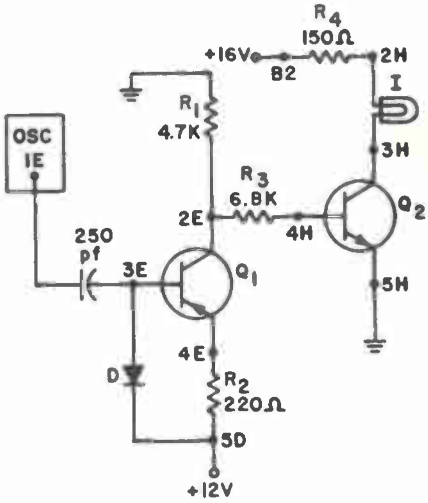


Fig. 55-1. The circuit you use for Step 1.

NPN transistor used in Experiment 53.

Connect square 5H to the outer ground foil, using a short length of wire. Solder a 150-ohm resistor between square 2H and terminal B2. Prepare the lamp socket for mounting as follows: Bend each terminal outward at a 90° angle about 1/8 inch from the end. Also, tin each terminal with solder. Solder the terminals of the lamp socket to squares 2H and 3H. Insert the lamp into the socket.

Solder a 6.8k-ohm resistor between squares 4H and 2E. Solder a 4.7k-ohm resistor between the ground foil and square 2E.

Solder a 220-ohm resistor between squares 5D and 4E. Solder a signal diode between square 3E and square 5D, with the cathode lead to 5D.

Solder a 250 pf capacitor between square 3E of the experimental board and square 1E of the oscillator board. Solder a length of hookup wire from square 5D to lug 5 of circuit board EC24.

Mount the PNP transistor on the experimental circuit board, using Fig. 2A as a guide. Identify the leads and bend them to fit. Solder the collector to square 2E, the base to square 3E, and the emitter to square 4E. Check your work carefully, making sure there are no unsoldered connections, no short-circuits, and that the circuit is wired according to the schematic.

Step 1: To demonstrate the basic circuit operation.

Set the frequency selector switch to position 3 (10 kHz) and energize the circuit. The lamp should light. If necessary, readjust the 1k-ohm potentiometer on the oscillator circuit board slightly. Switch the oscillator frequency to 1 kHz and 100 Hz and observe the lamp. Note that it glows only on the high frequency signal.

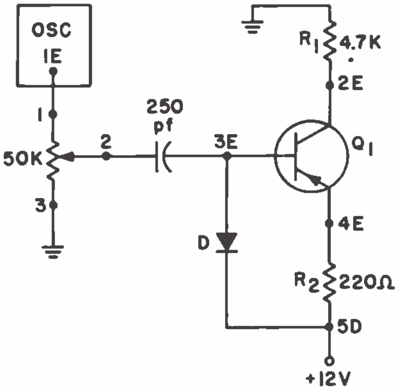


Fig. 55-2. Input circuit using the 50k-ohm pot.

Turn the circuit off and wire the 50k-ohm potentiometer, which is mounted on the front of your circuit board, into the circuit as shown on the schematic in Fig. 55-2. The terminals of the potentiometer are numbered clockwise when looking at the shaft end.

Unsolder the lead of the 250 pf capacitor from the oscillator board and solder it to terminal 2 of the potentiometer. Solder a length of hookup wire from terminal 3 of the potentiometer to ground. Solder a length of wire between terminal 1 of the potentiometer and square 1E of the oscillator circuit board.

Step 2: To show that the circuit responds to variations in signal strength.

Turn the circuit on, set the frequency to 10 kHz and vary the 50k-ohm potentiometer. Note that the brilliance of the lamp varies with the potentiometer adjustment.

Connect the ground clip of your tvom to lug 5 of EC24 and set the tvom to measure ac voltage on the 3-volt range. Touch the probe to square 3E to measure

VOLTAGE	MINIMUM	MAXIMUM
AC	.52	.6
DC	.4	.47

Fig. 55-3. Chart for input voltage measurements.

the ac voltage applied to the base of transistor Q_1. Notice the voltage variation as you rotate the potentiometer. Record the maximum value of ac voltage in Fig. 55-3. Reduce the signal strength with the potentiometer as you observe the lamp's brilliance. When the lamp just goes out, read the value of ac voltage at the base of Q_1. Record this as the minimum value of ac in Fig. 55-3.

Set your tvom to measure negative dc on the 3V range and measure the dc voltage corresponding to the minimum and maximum values of ac voltage. Record these values in the chart in Fig. 55-3.

Set the polarity switch on the tvom to normal, move the ground clip to the chassis and measure the Q_1 dc base voltage again. Record your reading in the chart in Fig. 55-4. Measure and record the voltages (with respect to the chassis) at the collector of Q_1 at square 2E; the base of Q_2 at square 4H; and the collector of Q_2 at square 3H with the minimum and maximum ac signal voltages applied.

Step 3: To show the effect of typical circuit defects. You will simulate defects

(A) To simulate a shorted diode, carefully short the signal diode lead with a screwdriver or a length of wire. Energize the circuit, vary the potentiometer and note that the bulb does not light. Measure the dc voltage at the base of transistor Q_1. The voltage should be approximately +12V. Remove the short circuit across the diode. 14.1

(B) To show the effect of a shorted transistor, Q_1. Connect a 1-megohm resistor between the ground foil and square 3E. When you energize the circuit, the lamp should light. Vary the signal level and change frequencies. The lamp should remain lighted and steady. Measure the voltages at the collector of Q_1 and the base and collector of Q_2 and compare them with the values recorded in the chart in Fig. 55-4. Remove the 1-megohm resistor.

(C) To show how a defective lamp affects the circuit voltages. Check to see that the lamp lights, and remove the lamp

MEASUREMENT	VALUE	
	MIN. SIGNAL	MAX. SIGNAL
Q_1 Base	12.9	13.2
Q_1 Collector	2	3.2
Q_2 Base	.30	.37
Q_2 Collector	16.0	14.5

Fig. 55-4. The chart for Step 2.

from the socket. Measure the voltage at the collector of Q_1 and at the base and collector of Q_2. You should find that the Q_2 collector voltage falls to zero while the Q_1 collector and Q_2 base voltages rise slightly. Turn the circuit off and replace the lamp.

(D) To show the effect of a base-emitter short-circuit in transistor Q_2. Connect a short length of hookup wire from ground to the base of transistor Q_2 at square 4H. Energize the circuit, vary the signal level and switch frequencies, and notice that the lamp remains off. Measure the Q_1 and Q_2 collector voltages. The Q_2 voltage should be abnormally high while the Q_1 voltage is normal.

Turn your equipment off and remove the short between the base of Q_2 and ground.

Discussion: In this experiment, you demonstrated a simple stereo indicator circuit. The circuit lighted the lamp whenever the proper signal voltage was applied to it.

The circuit consists of a shunt detector, diode D, and a two-stage direct-coupled amplifier with a lamp as part of the collector load of the output transistor. Transistor Q_1 is a PNP type while Q_2 is an NPN type. Normally, both transistors are turned off and little current flows through the lamp. When a signal is applied, Q_1 conducts and turns on Q_2, which causes current to flow through the lamp.

Diode D rectifies the ac signal voltage applied to it and makes the base of Q_1 negative with respect to the emitter. Because Q_1 is a PNP transistor, this negative voltage causes it to conduct. Current flows from ground through R_1 to the collector and from the emitter through resistor R_2, to the positive supply voltage terminal.

The collector of Q_1 becomes positive with respect to ground and this voltage is coupled through resistor R_3 and applied to the base of Q_2. Q_2 is an NPN transistor and the positive voltage fed to the base makes it conduct heavily. A large collector current flows through the lamp and the 150-ohm resistor to the positive supply voltage.

The information which you recorded in the chart in Fig. 55-4 confirms the preceding discussion of how the circuit works.

In Steps 1 and 2, you found that the circuit responds only to a moderately high amplitude 10 kHz signal. It does not work on 1 kHz or 100 Hz because the value of the coupling capacitor is too small to pass these frequencies without severe attenuation. The threshold or minimum required signal level is established primarily by the base cutoff characteristic of the input transistor, the reverse bias developed across the emitter resistor and the impedance of the coupling capacitor at the signal frequency. The threshold level of your circuit should be about .45V ac at the base of transistor Q_1.

In Step 3, you saw the effects of several common circuit defects. A shorted diode will not rectify the applied ac signal. Therefore, Q_1 will not become forward-biased and the lamp will not light. The circuit becomes completely inoperative.

A short in transistor Q_1, which you represented by applying a high forward bias, will keep the lamp turned on in the absence of signal. Q_1 will conduct continuously and the positive voltage dropped across the 4.7k-ohm collector load resistor, R_1, will keep Q_2 conducting heavily.

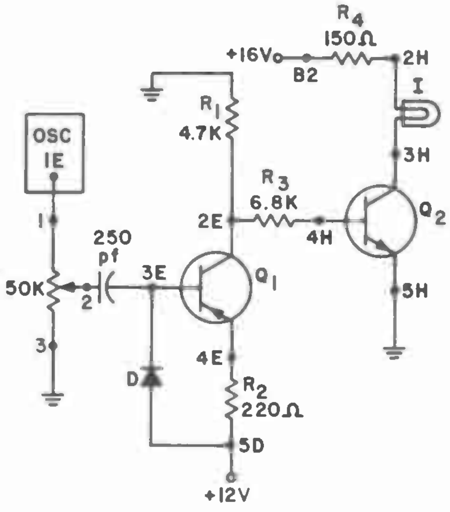


Fig. 55-5. The circuit for Statement 55.

In Step 3C, you found that a burned-out bulb will result in normal voltages throughout the circuit except at the collector of Q_2. The lamp is in series with the supply voltage and any break in that circuit removes the Q_2 collector voltage.

A shorted base-emitter in transistor Q_2 cuts Q_2 off and causes the lamp to remain turned off. The Q_2 collector voltage increases. Q_2 does not conduct so there is not enough collector current to light the lamp.

Instructions for Statement 55: For this Report Statement, you will reverse the connections of the diode as shown in Fig. 55-5 and determine how it affects the circuit operation.

Remove diode D from the circuit and reinstall it with the cathode lead to the base of Q_1 and the anode lead to the emitter supply voltage at square 5D. Turn the circuit on, test its operation on all three frequencies and answer the Statement. Be sure to place your answer on the answer sheet.

Turn your equipment off.

Statement No. 55: When I reversed the connections to the diode, I found that the circuit:

(1) worked normally.
(2) responded to all frequencies.
[✓ *(3)*] *did not respond to signals.*

This concludes the experiments on audio circuits. Dismantle your circuits to prepare for the new circuits which you will build for the next group of experiments.

Unsolder and disconnect the hookup wire connecting the 1k-ohm potentiometer and terminal B3. Also, unsolder and remove the 250 pf mica capacitor. Remove the oscillator circuit board along with the three-position switch and the potentiometer brackets from the top of the chassis.

Unsolder and remove all parts and leads (including the transistors) from the center circuit board. Remove the 50k-ohm potentiometer. Remove the board and the potentiometer mounting bracket.

Unsolder and remove both leads connecting terminals B2 and B3 to the low voltage supply.

Building An RF Oscillator And I-F Amplifier

In the next group of experiments, you will work with rf and i-f circuits. Thus, you will need a source of rf voltage. You will also work with a vacuum tube amplifier so you will need a circuit board having a tube socket mounted on it.

At this time, you should have terminal strips A, B, and F mounted on your chassis. The low voltage power supply is wired on circuit board EC24 and the high voltage supply is wired on terminal strip A. The green filament leads of the power transformer are connected to terminals B5 and B6. You will install one circuit board, modify your power supplies and wire the rf oscillator and i-f amplifier circuit for the next experiment.

MOUNTING THE PARTS

Refer to Fig. 9 as you carry out the following assembly steps. First, gather the following parts:

1	Oscillator coil with mtg. hardware (C043)
1	I-F transformer with mtg. hardware (TR13)
1	Tuning capacitor
1	1k-ohm potentiometer with mtg. hardware
1	Paper dial scale
1	Terminal lug
2	Knobs
4	No. 6 lockwashers
3	3/16″ 6-32 screws
4	4-40 screws
4	4-40 nuts
1	Circuit Board (EC25)

First, remove the 1k-ohm potentiometer from the audio oscillator board.

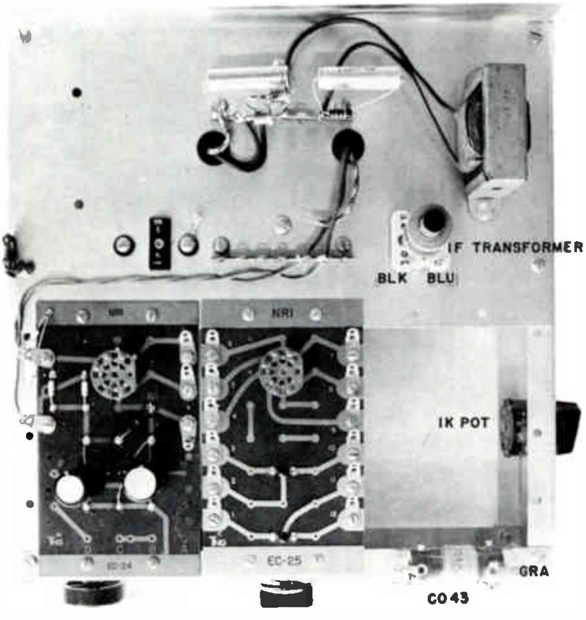


Fig. 9. The parts mounted on the chassis.

Unsolder the connections carefully. Also, remove the knob from the rotary switch on the oscillator board.

Mount circuit board EC25 on the chassis. Mount the board over holes S, T, AE, and AF, using four 4-40 screws and nuts.

Mount the rf oscillator coil, CO43, on top of the chassis at holes AG and AH. Position the coil so that the terminals color-coded yellow, gray and black are toward the right. Place a terminal lug over the screw at hole AH. Attach 4-40 nuts and tighten.

Mount the 1k-ohm potentiometer in hole AZ from the inside of the chassis. Use a control lockwasher and nut. Position the potentiometer so that the terminals are toward the top of the chassis rail.

Mount the i-f transformer on top of the chassis at hole L. Remove one of the nuts from the mounting screw of the transformer. Slip the mounting screw through the hole and rotate the transformer so that the terminals color-coded blue and black are toward the front rail of the chassis. Attach a lockwasher and the nut you removed from the screw and tighten securely.

Install the tuning capacitor at the front on the inside of the chassis at hole AV. At the same time, install the paper dial scale outside the chassis, using the same mounting screws. Refer to Fig. 10. Place No. 6 lockwashers over three 3/16" X 6-32 screws. Push the screws through the small holes in the dial scale and the three holes in the front of the chassis. Run these screws into the threaded holes in the front of the frame of the tuning capacitor. Rotate the shaft of the capacitor fully counterclockwise and place a pointer knob on the shaft. Position the knob so it points to zero on the scale and tighten the setscrew.

In a similar manner, install a pointer knob on the shaft of the 1k-ohm potentiometer. Rotate the shaft fully counter-

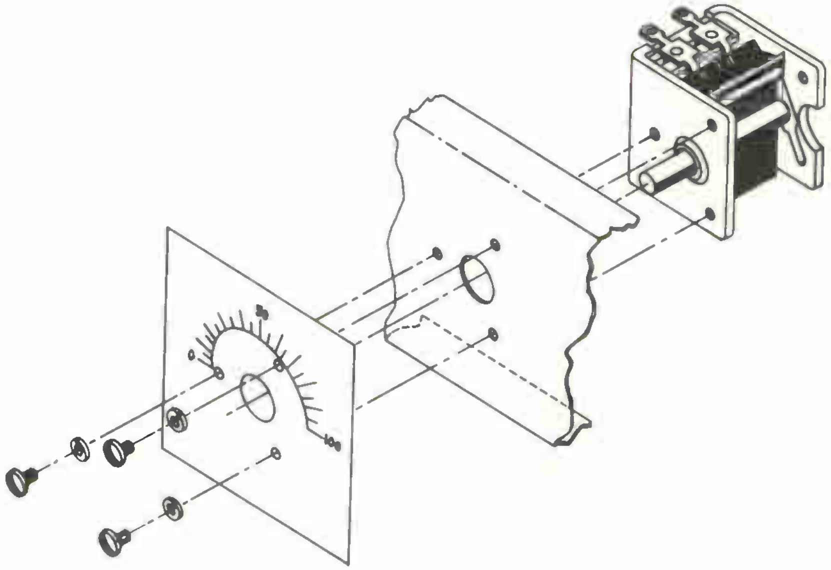


Fig. 10. Mounting the tuning capacitor on the front panel.

clockwise and install the knob in the 7 o'clock position.

WIRING THE CIRCUITS

You will begin your wiring by modifying the high and low voltage power supplies. Then you will wire the i-f oscillator and i-f amplifier circuits.

Gather the following parts:

1	**12BA6 tube**
1	**1-megohm resistor**
2	**10k-ohm resistors**
1	**3.3k-ohm resistor**
1	**470-ohm resistor**
1	**.1-mfd tubular capacitor**
2	**.01-mfd disc capacitors**
1	**.001-mfd disc capacitor**
1	**470 pf disc capacitor**

Power Supplies. The power supply circuits are shown in the schematic diagram in Fig. 11. First short terminal A4 to ground with a screwdriver to discharge the filter capacitor. Then unsolder and disconnect the red and red/yellow power transformer leads from terminals A1 and A2. Also disconnect and remove the rectifier connected between terminals A2 and A4. Solder the red transformer lead to terminal A1 and the red/yellow lead to terminal A2.

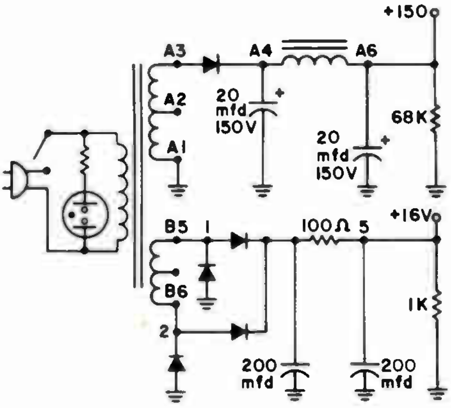


Fig. 11. High and low voltage power supplies.

Next, unsolder and disconnect the leads of the filter choke from terminals B2 and B3 and reconnect them to terminals A4 and A6. Terminal A6 is the +150V source (B+).

Reconnect the 100-ohm resistor between the positive leads of the input and output filter capacitors on circuit board EC24. Lug 5 of EC24 is the +16V terminal.

RF Circuits. To wire the rf oscillator and i-f amplifier circuits follow the schematic diagram in Fig. 12. The terminals are identified in the parts layout diagram in Fig. 9. The tuning capacitor is grounded through its frame and mounting to the chassis. The coil windings shown in the transistor circuit are windings of the oscillator coil on the front of the chassis. The windings shown in the plate circuit of the tube are the windings of the i-f transformer mounted at hole L.

All wiring, unless otherwise indicated, is on circuit board EC25. Where a ground is indicated, use a grounded terminal or solder directly to the foil at the end of the printed circuit board.

To wire the circuit, proceed as follows:

Connect a 10k-ohm resistor and a .01-mfd capacitor in parallel between lug 11 and ground. Connect a 10k-ohm resistor between lug 11 of EC25 and lug 5 of EC24.

Connect a 3.3k-ohm resistor and a .001-mfd capacitor in parallel between lug 12 and ground. Connect a 470 pf capacitor between lugs 1 and 12.

Connect a length of hookup wire from lug 1 to the green terminal of the oscillator coil.

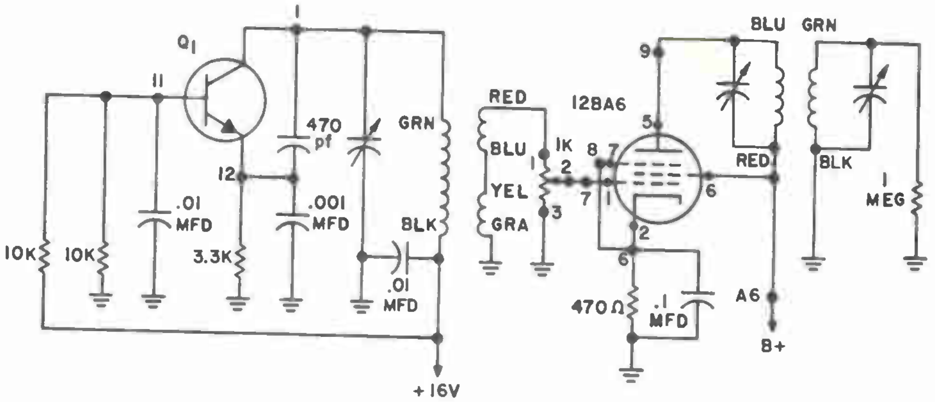


Fig. 12. The rf oscillator and amplifier circuit.

Prepare a 3-inch length of hookup wire. Push one end through the hole near lug 1 of the circuit board from the phenolic side of the board and solder. Solder the other end to the terminal at the lower rear corner of the tuning capacitor.

Connect a length of hookup wire from the black terminal of the oscillator coil, CO43, to lug 5 of EC24. Solder a .01-mfd capacitor between the black terminal and the ground lug. Connect a short length of wire between the gray terminal and the ground lug.

Solder a length of wire between the blue and yellow terminals of the oscillator coil. Solder a length of wire between the red terminal of the coil and terminal 1 of the 1k-ohm potentiometer mounted on the right side of the chassis. (The terminals are numbered clockwise from the shaft end of the potentiometer.) Solder a length of wire between terminal 2 of the potentiometer and lug 7 of the EC25 circuit board. Connect and solder a wire from terminal 3 of the potentiometer to ground.

Connect a length of wire between lugs 6 and 8 of EC25. Connect a 470-ohm resistor and a .1-mfd tubular capacitor in parallel between lug 6 and ground.

Connect a length of wire from the red terminal of the i-f transformer to terminal A6. Notice that pin 6 of the tube does not connect to any of the lugs on EC25. There are two holes in the foil instead. Solder a length of wire from one of these holes to the red terminal of the i-f transformer. Connect a wire from lug 9 to the blue terminal of the i-f transformer.

Connect a short length of wire from the black terminal of the i-f transformer to ground. Connect a 1-megohm resistor from the green terminal of the transformer to ground.

To wire the filament circuit, solder a length of wire from terminal B5 to lug 4 and solder a length of hookup wire from terminal B6 to lug 5. Be sure the wires already connected do not come loose from terminals B5 and B6. Insert the 12BA6 tube in the socket on the experimental circuit board.

When you complete the wiring, check your work carefully, then energize the circuit and observe that the filament in the tube lights up.

To test your circuit, measure the oscillator output voltage. Set your tvom to measure 3V ac and measure the voltage between the red terminal of the oscillator coil and the chassis. You should read

1V or more. If not, check for +16V at lug 5 of EC24 and check the oscillator wiring. Assuming that the oscillator is working, measure the ac voltage at the plate of the amplifier. Turn the shaft of the 1k-ohm potentiometer fully clockwise. While measuring the voltage, rotate the shaft of the tuning capacitor throughout its range. If you get a reading of over 5 volts, you can assume that the oscillator and amplifier are both working correctly.

Turn your equipment off.

HOW THE CIRCUITS WORK

At present you have a high voltage power supply supplying about +150V dc to the plate and screen circuits of the vacuum tube. From the schematic in Fig. 11, you can see that it is a half-wave supply with a pi-type filter network. The full HV secondary winding of the power transformer is used for maximum output voltage.

The low voltage supply is also a bridge type with a pi-filter network. The filter uses two capacitors and a small series resistor instead of a choke.

The rf oscillator is a Colpitts, using an NPN transistor. The transistor is connected in a grounded base configuration. The base is held at ac ground by the .01-mfd capacitor in shunt with the base bias resistors.

The resonant circuit for the oscillator consists of the primary winding of the oscillator coil in parallel with the 470 pf and .001-mfd capacitors and the tuning capacitor. The .01-mfd capacitor at the black transformer terminal has such a low reactance at the signal frequency that this end of the coil winding is at signal ground. The 470 pf and the .001-mfd capacitors form a capacitive voltage divider. This divider taps off and feeds back part of the collector output signal voltage to the emitter to sustain oscillations.

Combination bias is used. Forward bias voltage is supplied by the voltage divider across the base circuit and the resistor connected between ground and the emitter provides reverse bias.

The tuning capacitor varies the frequency of the oscillator by varying the total capacitance in shunt with the oscillator coil. The output signal is coupled inductively from the primary to the secondary winding. Note that the two secondary windings are series-connected for greatest output. This voltage is developed across the 1k-ohm potentiometer which will serve as an oscillator output level control.

The rf amplifier uses the 12BA6 tube connected as a pentode. The amplifier uses cathode bias, developed by cathode current flowing through the 470-ohm resistor. The i-f transformer in the plate circuit can be tuned to resonance by the trimmer capacitors connected across the windings.

EXPERIMENT 56

Purpose: To show that in a double-tuned circuit: (a) loose coupling gives low output and a sharp response; (b) there is a degree of coupling – called critical coupling – that gives maximum output voltage; and (c) overcoupling gives a broad double-peaked response; and to show that loading the secondary of a double-tuned transformer reduces the output and flattens the response.

Introductory Discussion: The output of an amplifier stage is of no practical use unless it can be effectively coupled to a load. This coupling can be accomplished in a variety of ways, as you have learned in your regular lessons and in previous experiments.

The i-f amplifier stages of almost all superheterodyne AM and FM sound receivers are coupled through a transformer having both the primary and secondary windings tuned to resonance at the intermediate frequency. A winding can be tuned by changing the setting of a variable capacitor connected across it, or by varying the position of a powdered-iron slug inside the winding, thus varying its inductance.

When a given voltage is applied across the primary winding of a coupling transformer, the amount of voltage developed across the secondary winding depends upon a number of factors, the most important of which are: (a) the degree of coupling between the two coils; (b) the Q of the transformer; and (c) the accuracy with which the primary and secondary coils are adjusted to resonance with the frequency of the input voltage.

In this experiment, you will vary the degree of coupling between the coils and note the effect upon the output voltage and upon the response over a wide range of frequencies.

The i-f transformer is designed to operate most effectively within the frequency range from 400 to 500 kHz.

The tuning range of the rf oscillator is from about 380 kHz to about 570 kHz, as shown in the graph in Fig. 56-1. From this graph, you can see that if you set the variable capacitor to 50 on its reference dial scale, the frequency produced by the oscillator will be very close to the 456 kHz frequency at which the i-f transformer was intended to be operated.

The response curve of a circuit is a graph in which output voltage is plotted against frequency. Normally, the frequency is varied in even steps and the voltage is plotted at each point. A smooth curve is then drawn connecting these points.

To get the response curves for a given degree of coupling, you will set the pointer knob on the tuning capacitor shaft to 50 on the dial scale, and adjust both i-f transformer trimmers for maximum output voltage at that frequency. Then, without touching the settings of

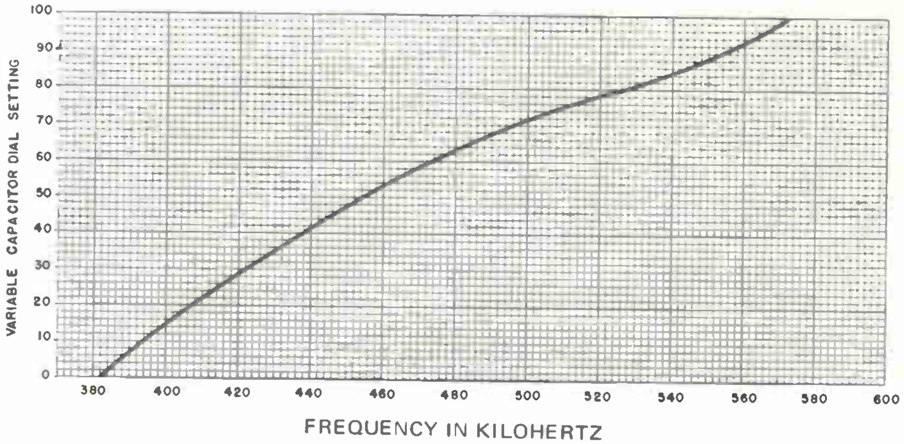


Fig. 56-1. Tuning range of the rf oscillator with .001-mfd capacitor and 470 pf capacitor across oscillator coil and tuning capacitor.

the i-f trimmers, you will tune the oscillator throughout its range and measure the rf output voltage as you do so. To show the effect of loading on the circuit response, you will connect a smaller resistor across the transformer output winding. You will again measure the rf output voltage. By comparing the results of the two steps, you will be able to see the circuit response for the two circuit conditions.

Experimental Procedure: For this experiment, you will need your tvom, your chassis and the following parts:

1 47k-ohm resistor
1 Test clip (CL8)

In this experiment, you will use the oscillator and amplifier circuits which you constructed earlier. The circuit is shown in Fig. 12.

To align the i-f transformer to approximately 456 kHz, proceed as follows:

First set the coils of the i-f transformer as far apart as you can to get minimum coupling. Only the coil at the open end of the fiber form is movable. Pull this coil gently and carefully toward the open end of the form until the distance between the two coils, measured between the inside faces of the coils, is 1-1/16 inches. This is distance D in Fig. 56-2. The open end of the fiber form is flared outward slightly to keep the coil from falling off. Don't pull the coil beyond this flare. If it does not reach 1-1/16 inches, use the maximum distance you can get as minimum coupling.

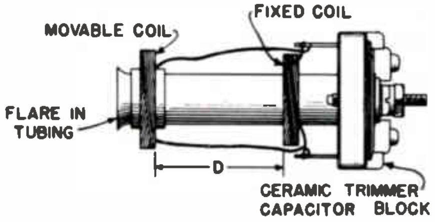


Fig. 56-2. Measure distance D when adjusting the i-f coils for different degrees of coupling.

Set the knob pointer on the variable capacitor that controls the rf oscillator frequency to exactly 50 on the calibrated scale. Use a small screwdriver through chassis holes L_1 from the bottom and L_2, and turn both trimmers of the i-f transformer as far as they will go easily in the clockwise direction. Then back each one off 1/4 turn. Turn the rf oscillator output control (the 1k-ohm potentiometer) for full output – all the way clockwise.

Slip the test clip on the probe of your tvom. Then you can clip the probe to the test point and have both hands free.

Connect the ground clip of the tvom to the chassis, and the probe to the green terminal of the i-f transformer which is the output terminal. Turn on the power.

Turn the trimmer adjustment screw through chassis hole L_2. Turn this adjustment in the direction that gives an increased voltage. Switch to higher voltage ranges of the tvom, when necessary, to keep the meter pointer from going off scale. If you find the meter pointer tends to go off scale when the 120-volt range is used, readjust the 1k-ohm potentiometer to reduce the output from the oscillator so that you will stay on this voltage range. Continue adjusting the trimmer through hole L_2 until you find the maximum reading.

Adjust the trimmer through chassis hole L_1 for maximum output; then readjust the trimmer through hole L_2 for maximum output. This is necessary to compensate for the interaction between the coils of the i-f transformer. If the output exceeds 120V, set the 1k-ohm potentiometer for a lower input. Now, make a final touchup adjustment of both trimmers to be sure that you have them set at the positions that give the maximum meter reading.

The adjustments you have made tune the i-f transformer to resonance with the frequency produced by the rf oscillator. For the rest of the experiment, the tuning of the i-f transformer will remain essentially the same as you have it now.

Step 1: To determine the frequency response of the rf amplifier stage.

Proceed as follows:

First, set the variable tuning capacitor at zero (0) on the calibrated scale (maximum capacity), so that the rf oscillator will produce its lowest frequency.

Set the rf oscillator output control (the 1k-ohm potentiometer) to apply exactly 1 volt (measured on the 3V range) to the control grid, pin 1, of the 12BA6 tube. If you make this adjustment accurately, you will not need to recheck it during any one set of frequency measurements at a particular coil spacing. The tuning range of the oscillator will be restricted to the low frequencies, at which the output of the oscillator is essentially constant.

Reconnect the probe of your tvom to the 1-megohm load resistor at the green transformer terminal, set the range switch to 12V, and measure the rf voltage. Enter your reading for the 0 dial setting in the first space in the first column of Fig. 56-3. If this voltage is less than 1 volt on the 12V scale, estimate the value as well as you can. *Don't switch to a lower range – take as many measurements as possible on the same scale.*

Set the oscillator tuning control to 30, 40, 50, 60, 70, and 100, and record the output voltage for each setting in the first column of Fig. 56-3. As the frequency of the oscillator approaches that to which the i-f transformer has been tuned, the output voltage should become high enough to make it possible to use the 120V range. The highest voltage you get should be when the oscillator frequency control is set at 50, the frequency to which the i-f transformer was adjusted.

DIAL SETTING	STEP 1 1-1/16"	STEP 2 5/8"
0	.82	5.2
30	.52	5.2
40	.94	7
50	.92	7
60	.56	5.4
70	0	5.7
100	0	2.7

Fig. 56-3. The chart for Steps 1 and 2 with a 1 megohm load on the transformer.

When you have finished this frequency run, return the oscillator tuning control to 0, and turn off the power supply.

The fixed coil of the i-f transformer is the primary winding, which is in the plate circuit of the amplifier stage, and is above ground potential by an amount equal to the dc plate voltage. For safety's sake, therefore, **ALWAYS TURN OFF THE POWER SUPPLY** before touching the coils to change the coupling.

Step 2: To show that closer spacing produces greater output.

Turn off the power and set the coils 5/8 inch apart. Rotate the tuning knob smoothly from zero to 100 on the dial scale and observe how the output varies. You should see the voltage rise to a peak at a dial setting of 50 and fall to a low value, as in Step 1. However, the peak rf voltage should be much higher than that obtained in Step 1. Record the voltages at zero, 30, 40, 50, 60, 70 and 100 on the dial scale in the second column of the chart in Fig. 56-3.

Step 3: To show the effects of overcoupling.

Set the coils 3/8 inch apart, and, after checking the rf input voltage to see that it is still 1 volt, repeat the frequency run: Rotate the tuning knob smoothly from zero to 100 while observing the rf output voltage. This time there should be two voltage peaks, with one below and one above the resonant frequency of the i-f transformer.

Repeat the test and record the frequency settings for the two peaks. These peaks may or may not be of equal value and may or may not be spaced an equal distance away from the resonant frequency setting of 50 at which the previous signal peaks were obtained. Furthermore, the peaks may not occur at one of the main scale divisions. Record the frequencies at which the peaks occur and the peak voltages in the chart in Fig. 56-4. Also, record the voltage with the dial set to 50.

	LOW PEAK	CENTER	HIGH PEAK
DIAL SETTING			
VOLTAGE			

not obtained

Fig. 56-4. The chart for Step 3.

	LOW PEAK	CENTER	HIGH PEAK
DIAL SETTING			
VOLTAGE			

only one pk.

Fig. 56-5. The chart for use with Step 4.

Step 4: To show the effect of loading an overcoupled circuit.

Remove the 1-megohm resistor across the transformer secondary and replace it with a 47k-ohm resistor. This increase in the load increases the current drawn from the transformer. Repeat the frequency run with the coil spacing still at 3/8 inch.

Again, you should find two voltage peaks, but now the maximum voltages should be much less than those you measured in Step 3. The difference between the maximum voltages and the voltage at resonance, 50 on the scale, should be much less than it was in Step 3, when the load was much less. The actual peak voltage on each side of resonance may not occur at a main scale division.

Find and record the actual positions and the peak voltages as in the previous step. Record your readings in Fig. 56-5. Also, record the voltage at the dial setting of 50.

Turn your equipment off.

Discussion: You have observed the output of an i-f amplifier with a double-tuned output transformer under various conditions. In Step 1, you had maximum spacing between the transformer coils, and hence minimum coupling. The response curve of the transformer is represented by curve 1 in Fig. 56-6.

The curve shows that the transformer passes little signal voltage at the dial setting of zero. The voltage rises to a maximum at 50, decreasing again as the oscillator is tuned higher. We can see that the transformer is resonant at 50 or that its center frequency is at a dial setting of 50.

Note that at dial settings of about 45 and 55 the voltage is about 70% of its maximum value. These points on the graph are called the half power points, in that the voltage and current are about 70% of the voltage and current at resonance. Thus, the transformer bandpass, the band of frequencies between the half power points, is about 20 kHz, as determined from the chart in Fig. 56-1.

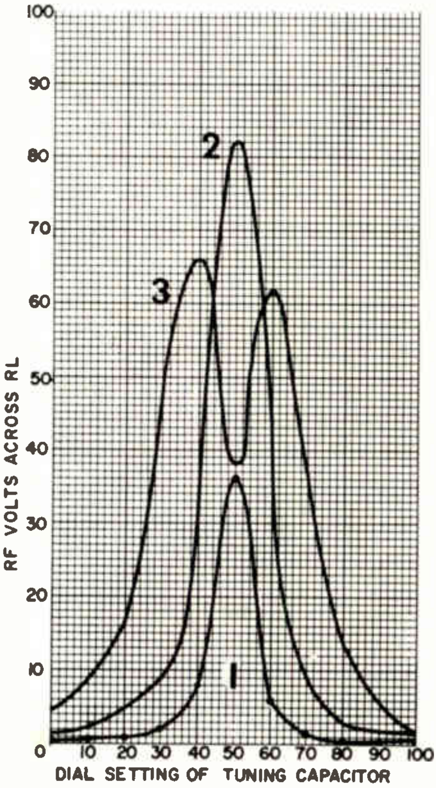


Fig. 56-6. Curves plotted from typical values for different degrees of coupling with a 1-megohm load resistor.

In Step 2, closer spacing of the i-f transformer coils was used. This change produced a higher peak voltage and a slightly broader bandpass, as shown by curve 2 in Fig. 56-6. Note that the peak still occurred at the same frequency, with a dial setting of 50. The coil spacing was very close to "critical" coupling, which is the spacing that produces maximum output at the center frequency.

With a coil spacing of 3/8 inch in Step 3 you should have obtained a double peak response as in curve 3 in Fig. 56-6. The coils were overcoupled and they interacted with each other. You will note that the output at the center frequency was lower than in Step 2. The resonant frequency of one coil became lower, and the resonant frequency of the other became higher than their natural frequencies. This resulted in the peaks on either side of the center frequency. Because of the two peaks, the bandwidth of the overcoupled transformer is greater than it is with critical coupling.

In Step 4, if you plotted the points, you would have found a response curve similar to the graph in Fig. 56-7. Comparing this with curve 3 of Fig. 56-6, you can see that loading the output of the transformer lowered the output voltage at the peaks and broadened the bandwidth.

Loading in this manner is a technique used frequently to increase the bandwidth of a resonant circuit. It reduces the output voltage and makes the bandpass curve more gradual.

Instructions for Statement 56: For this Statement, you will determine the effect of loading the transformer when there is wide spacing between the coils.

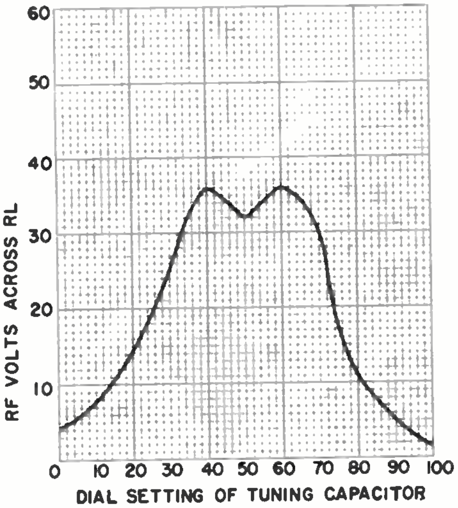


Fig. 56-7. Typical curves for a 47k-ohm load resistor and 3/8-inch spacing.

Set the coils 5/8 inch apart. At this spacing, you should have a single-peak response curve. With the 47k-ohm resistor in the circuit, run the frequency test and note the voltage across the load resistor. Note the voltage at dial settings of 10, 40, 50, 60 and 90.

Compare these voltage readings with those you recorded for Step 2 in Fig. 56-3 and answer the Report Statement.

Statement No. 56: When I loaded the secondary winding I found that the output voltage was:

[✓ *(1) lower than*]
(2) higher than
(3) the same as

the voltage I obtained for the same coupling but with a higher load resistance in Step 2 and the bandpass was

[✓ *(1) wider than*]
(2) narrower than
(3) the same as

the bandpass of the circuit in Step 2.

EXPERIMENT 57

Purpose: To show that an amplifier stage can provide both gain and amplitude limiting of an rf signal and to show diode limiting.

Introductory Discussion: A limiter is a special type of i-f amplifier stage used in many FM receivers. Its function is to limit the amplitude of the FM i-f signal, thereby removing the variations in the strength or amplitude of the signal reaching the demodulator. The block diagram in Fig. 57-1 shows the location of the limiter in the signal path of a typical FM receiver.

An FM signal has the intelligence in the variations in the frequency of the carrier wave about the assigned center frequency. The transmitted signal has uniform amplitude. Along the transmission path between the transmitting and receiving antennas, the signal picks up noise from vehicle ignition, static, etc. The noise takes the form of variations in the amplitude of the FM signal.

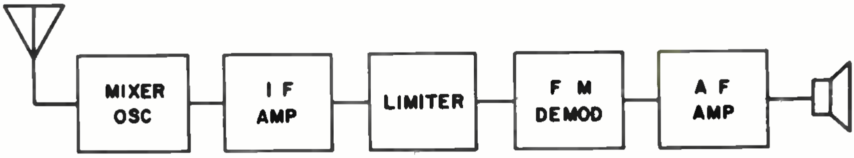


Fig. 57-1. Block diagram of a basic FM receiver.

For noise-free reception, it is necessary to either remove the noise before the signal is demodulated, or to use a demodulator which is not sensitive to amplitude variations. As you will see, both methods are used.

Limiting is usually accomplished in one of two ways:

One or two limiter stages are connected into the signal path between the i-f amplifier stages and the demodulator or diodes are placed across the secondary winding of one or more i-f transformers.

Experimental Procedure: For this experiment, you will need the experimental chassis, your tvom and the following parts:

1	**100k-ohm resistor**
1	**47k-ohm resistor**
2	**22k-ohm resistors**
1	**6.8k-ohm resistor**
2	**4.7k-ohm resistors**
1	**100-mfd electrolytic capacitor**
1	**.1-mfd tubular capacitor**
2	**Signal diodes (CR10)**

You should have circuit board EC25 on your chassis and the board should have 2 NPN transistors mounted on it. You should also have the 1k-ohm potentiometer mounted inside the right side of the chassis at hole AZ.

Unsolder and remove all parts and leads connected to lugs 6, 7, 8 and 9 of the circuit board. Also, unsolder all connections to the i-f transformer and remove the transformer from the chassis. Remove the 12BA6 tube from the socket.

Construct the transistor amplifier circuit shown in the schematic in Fig. 57-2. Note that the oscillator circuit is unchanged. The amplifier transistor (Q_2) is already on the circuit board. Its base, collector and emitter leads are connected to lugs 2, 3 and 10, respectively. Ground lug 10 with a short length of wire. Connect a 4.7k-ohm resistor between lug 2 and ground.

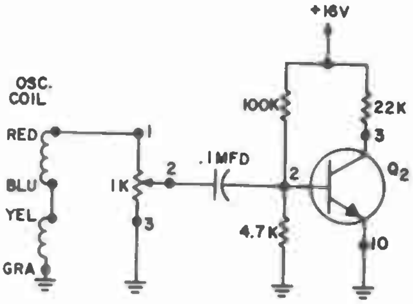


Fig. 57-2. The limiter-amplifier circuit diagram.

Connect a 100k-ohm resistor between lug 2 of EC25 and lug 5 of EC24. Connect a 22K-ohm resistor between lug 3 of EC25 and lug 5 of EC24.

Connect one end of a .1-mfd tubular capacitor to terminal 2 of the 1k-ohm potentiometer. Notice that there are two solder pads in the foil strip connecting the base of Q_2 to lug 2. Place the .1-mfd capacitor in such a position, ***under the board***, that the lead is near the hole next to the base of Q_2. Poke the lead of the capacitor through the hole in EC25 near the base of Q_2 and solder.

Be sure to check your work carefully against the schematic diagram.

Step 1: To show that the amplifier gain varies with the input signal level.

Energize the circuit and check it as follows: Rotate the knob on the 1k-ohm potentiometer fully clockwise and measure the ac voltage at the base and collector of the rf amplifier, Q_2. You should have at least .2V at the base (lug 2) and 2V at the collector (lug 3).

INPUT VOLTAGE	OUTPUT VOLTAGE	GAIN
.05V	1.14	22.8
.1	1.18	11.8
.2	1.21	6.05
.4	1.28	3.2
.6	1.35	2.25
.8	1.41	1.7625
1.0	1.45	1.45

Fig. 57-3. Chart for Step 1.

Now move the tvom probe to terminal 2 of the 1k-ohm potentiometer. Adjust the potentiometer for an input signal of .05V. Measure the collector voltage and record it on the chart in Fig. 57-3. Readjust the input to the base to .1V and measure and record the corresponding collector signal voltage. In a similar manner, set the input to each of the voltage levels given in the first column in Fig. 57-3 and measure and record the resulting ac output voltages at the collector.

When you complete the chart, compute the gain of the amplifier at the various input levels. Record the gain for each input voltage in the third column.

Step 2: To demonstrate how low supply voltage affects limiter action.

For this step, you will use the circuit shown in Fig. 57-4. Unsolder the lead of the 22k-ohm resistor from lug 3 of EC25 and connect it to lug 4 of EC24. Connect a 6.8k-ohm resistor and a 100-mfd electrolytic capacitor between lug 4 of EC24 and ground. Note that the positive capacitor lead goes to lug 4. Connect a 4.7k-ohm resistor between lug 4 of EC24 and lug 3 of EC25. Energize the circuit and measure the dc voltage at lug 4 of EC24. This is the supply voltage for the limiter stage. Jot down the value in the margin. Measure the ac voltage at lug 4 of EC24. You should read zero, as this point is at signal ground.

2.5V

Now apply each of the input voltage levels given in the chart in Fig. 57-5 and measure and record the corresponding output voltages. You should find that limiting takes place at a low input signal level.

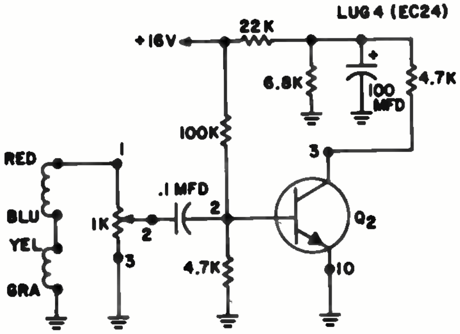


Fig. 57-4. The circuit for Step 2.

INPUT VOLTAGE	OUTPUT VOLTAGE
.05	.38
.1	.4
.2	.4
.4	.4
.6	.41
.8	.42
1.0	.43

Fig. 57-5. The chart for Step 2.

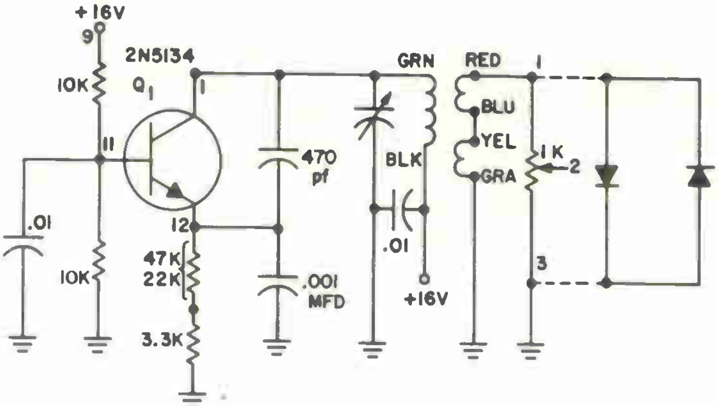


Fig. 57-6. The circuit used in Step 3.

Step 3: To show diode limiting.

For this step, you will connect diodes across the secondary winding of the oscillator transformer. You will then vary the oscillator output level and observe the effect of the diodes on the output signal level. You will use the circuit shown in Fig. 57-6.

Unsolder and disconnect the .1-mfd capacitor from terminal 2 of the 1k-ohm potentiometer and push the lead aside. Also disconnect the lead of the 3.3k-ohm emitter resistor from lug 12. Connect a 47k-ohm resistor between lug 12 and the free lead of the 3.3k-ohm resistor. Energize the circuit and measure the ac voltage across the 1k-ohm potentiometer, which is the output load resistance. You can connect the tvom between the red terminal of the oscillator coil and ground. Record your voltage reading on the first line of the second column of Fig. 57-7.

Connect two signal diodes across terminals 1 and 3 of the 1k-ohm potentiometer as shown in Fig. 57-6 by the broken lines. Measure the ac signal voltage across the potentiometer again. Record this value in the second column of Fig. 57-7.

Replace the 47k-ohm resistor in the emitter circuit of the oscillator with a 22k-ohm resistor. Repeat the measurements, first with the diodes disconnected, and then with the diodes connected across the transformer winding. Record both values on the second line of Fig. 57-7.

Unsolder and remove the 22k-ohm

SERIES RESISTOR	LOAD VOLTAGE	
	WITHOUT DIODES	WITH DIODES
47K	.3V	.23
22K	2V	0
None	0	0

Fig. 57-7. The chart for use with Step 3.

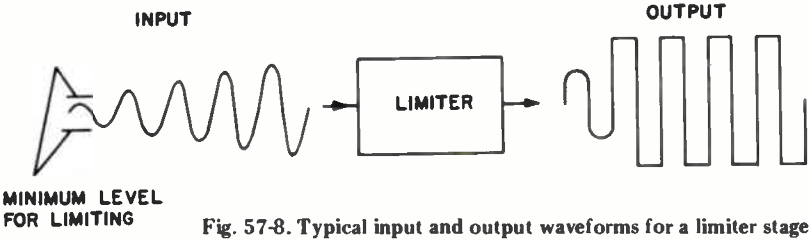


Fig. 57-8. Typical input and output waveforms for a limiter stage.

resistor and reconnect the 3.3k-ohm resistor to lug 12. Again measure the output voltage with and without the diodes and record your voltage readings in the chart.

Turn your equipment off.

Discussion: In this experiment, you demonstrated the action of a limiter-amplifier stage and diode limiting. You should have found that with both methods the output variation was significantly reduced by the limiter action.

The limiter stage which you used in Step 1 can be classified as an overdriven amplifier. The stage has high voltage gain and requires only a very low level of input signal for maximum output. When this level is exceeded, limiting occurs. If the limiter is properly biased, the transistor should be driven into cutoff on one-half of each cycle of the i-f signal and into saturation on the other half-cycle. Fig. 57-8 shows typical input and output signal voltage waveforms for this type of limiter.

Your chart in Fig. 57-3 shows that the amplifier has high gain for low level signals and that the gain drops off as the input signal level is increased. When the input is greater than about .4V, limiting takes place. The output at this point is about 6V. Thus, as long as the signal is .4V or more, the output will be maximum.

In Step 2, you found that the limiter was more effective than it was in Step 1. The transistor became saturated on the positive peaks of the input signal. On the negative peaks, the transistor was cut off and collector voltage rose to the level of the supply voltage, about +3.5V.

In Step 3, you found that the diodes across the transformer secondary winding caused a very noticeable decrease in the amount by which the transformer output voltage varied. At NRI we found that without the diodes, the voltage across the secondary varied from .3 to about 1.5V. This is a change of about 1 to 5. On the other hand, with the diodes in place, the variation was from .3V to .4V. This change was about one-third. Note that the minimum output level was about the same whether or not the diode limiting was used.

The diodes you used are silicon signal diodes which conduct when the voltage at the anode becomes about .6V more positive than the cathode. The diodes are connected with opposite polarities so that one will conduct whenever the voltage across them becomes either positive or negative by about .6V. Each diode conducts on one-half cycle. Therefore, the peak-to-peak voltage across the load will be about 1.2V. Due to the waveform, the tvom will indicate about .4V ac.

In many portable FM receivers, you will see diodes labeled "overload" connected across windings of one or more of the i-f transformers. In reality they are limiters and their function is to limit the amplitude of the signal to minimize distortion in the following stages.

Instructions for Statement 57: For this Report Statement, you will increase the value of the collector load resistor in the limiter circuit used in Step 2 and note the effect on the limiting action.

Remove the two diodes connected across the 1k-ohm potentiometer and reconnect the .1-mfd capacitor to the center terminal of the potentiometer.

INPUT VOLTAGE	OUTPUT VOLTAGE
.05	.12
.1	.12
.2	.12
.4	.12
.6	.12
.8	.12
1.0	.12

Fig. 57-9. The chart for Statement 57.

Replace the 4.7k-ohm resistor connected between the Q_2 collector terminal, lug 3, and lug 4 of EC24 with a 22k-ohm resistor.

Energize the equipment and make the ac voltage measurements necessary to complete the chart in Fig. 57-9. When you finish this, compare the charts in Fig. 57-3 and 57-9 and answer the statement.

Statement No. 57: When I increased the value of the collector load resistor, I found that the limiter circuit:

(1) had higher gain.

(2) limited more sharply.

(3) did not limit.

EXPERIMENT 58

Purpose: To demonstrate amplitude modulation and demodulation.

Introductory Discussion: An AM signal is one in which the amplitude of the fixed frequency carrier is varied by the intelligence or the audio modulating signal. This is illustrated in Fig. 58-1A. An rf carrier and an audio signal are applied to a modulator stage. In this stage the modulating signal causes the amplitude of the carrier to vary. The amount by which the rf amplitude varies is determined by the strength of the audio signal. The rate of amplitude variation is determined by the frequency of the audio signal.

Detection, which is the process of recovering the audio from the rf carrier, is illustrated in Fig. 58-1B. Notice that the modulated rf is fed into the demodulator circuit and the audio signal appears at the output. In the process, the rf carrier is filtered out.

In this experiment, you will use your rf

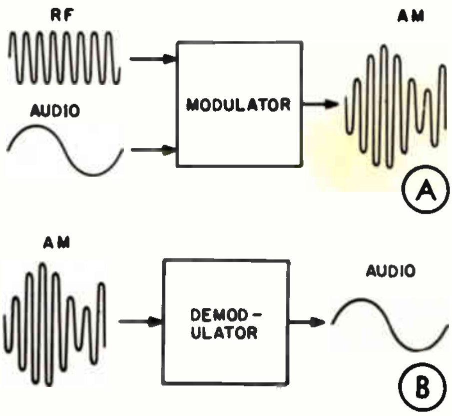


Fig. 58-1. (A) Amplitude modulation; (B) basic amplitude demodulation.

oscillator as an rf carrier signal source. This rf voltage will be modulated by a 60 Hz sine wave to produce an amplitude modulated signal similar to that shown in Fig. 58-1. The modulated rf will be transformer-coupled to a diode detector circuit. As you will demonstrate, the detector recovers the 60 Hz modulating signal.

Experimental Procedure: For this experiment, you will need the experimental chassis with the power supply and rf oscillator circuit, your tvom and the following:

1	**PNP transistor (TS22, 2N5138)**
1	**RF transformer (TR31)**
1	**150k-ohm resistor**
1	**100k-ohm resistor**
1	**15k-ohm resistor**
1	**4.7k-ohm resistor**
1	**1k-ohm resistor**
1	**.25 mfd tubular capacitor**
2	**.05 mfd disc capacitors**
1	**.001 mfd disc capacitor**
1	**470 pf disc capacitor**
1	**Trimmer capacitor (CN58)**
1	**50k-ohm potentiometer (PO100)**
1	**Signal diode (CR10)**
1	**4-lug terminal strip**
1	**3/8" X 6-32 screw**
1	**6-32 hex nut**

Before you begin the experiment, you must prepare the chassis and circuit board. Unsolder and remove transistor Q_2 and all parts and leads connected to lugs 2, 3 and 10 of the experimental circuit board and lug 4 of circuit board EC24. Be careful to avoid overheating the transistor.

The PNP transistor should have been removed from the other experimental circuit board (EC26). Solder the PNP transistor to circuit board EC25 as shown in Fig. 58-2.

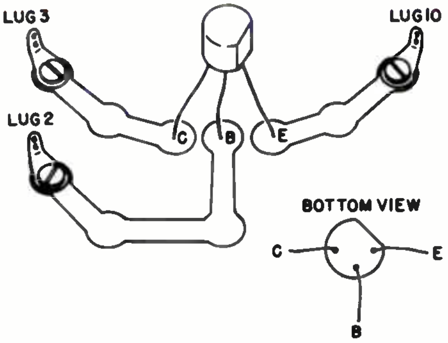


Fig. 58-2. Mounting the 2N5138 transistor.

Refer to Fig. 58-3 as you perform the next four steps.

Mount the rf transformer at holes AL and W. Position the transformer so the terminals color-coded red, yellow and blue are toward the front of the chassis. Remove the screw at hole W. Also remove one nut from each mounting screw on the rf transformer. Slip the mounting screws through the holes in the chassis, attach the nuts and tighten.

Remove the 1k-ohm potentiometer from hole AW, and install a 50k-ohm potentiometer in its place.

Mount the trimmer capacitor on top of the chassis at hole AK. Use the screw, lockwasher and nut just removed from the chassis.

Install a 4-lug terminal strip at hole U. Position the strip as shown. Attach with a 6-32 screw, lockwasher and nut. This is terminal strip C and its terminals are labeled on the photo.

Now wire the circuit shown in the schematic diagram in Fig. 58-4. The oscillator circuit is unchanged. However, note that only the blue/red winding of the oscillator transformer is used to couple the rf signal to the experimental circuit.

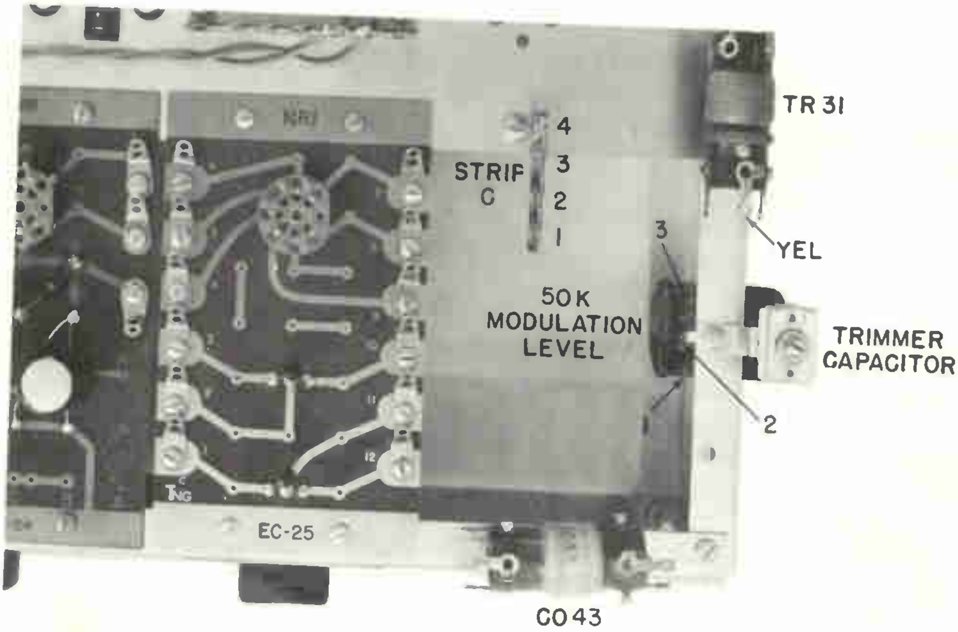


Fig. 58-3. Mounting the parts on the chassis.

The circuit is fairly complex. To avoid undesirable coupling, etc., perform the wiring carefully. Use short lengths of hookup wire when possible and route the leads where they will not cause interference.

Unsolder and disconnect all leads and parts from the gray, yellow, red and blue terminals of the oscillator coil.

Unsolder the lead of the 10k-ohm resistor from lug 5 of EC24 and solder it to the black terminal of the oscillator coil.

Connect a length of wire from lug 5 of EC24 to lug 9 of EC25.

Connect a 1k-ohm resistor between lug 9 and lug 10 of EC25.

Connect a .001-mfd capacitor between

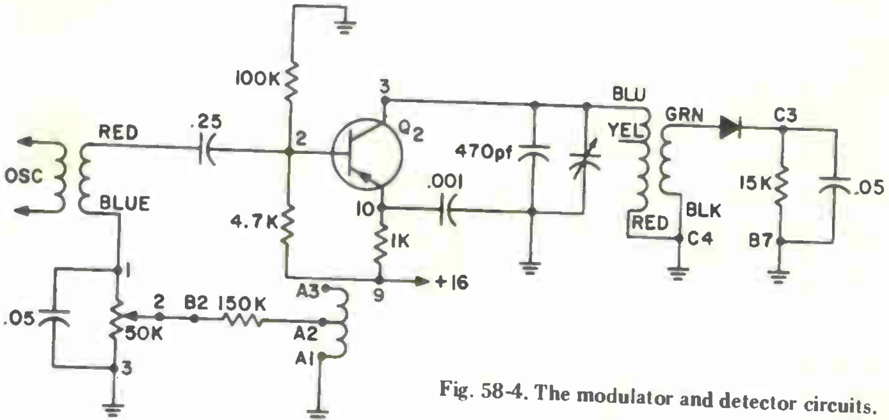


Fig. 58-4. The modulator and detector circuits.

lug 10 of EC25 and terminal C4. Solder lug 10.

Connect a 4.7k-ohm resistor between lug 5 of EC24 and lug 2 of EC25.

Solder a 100k-ohm resistor between lug 2 of EC25 and ground.

Connect a .25-mfd capacitor from the red terminal of the oscillator coil to the foil near lug 2 of EC25. Position the capacitor under the circuit board and push the lead up through the hole in the foil. Solder both connections.

Connect a length of wire from the blue terminal of the oscillator coil to the terminal of the 50k-ohm potentiometer nearest the front panel. Solder the potentiometer terminal.

Solder a .05-mfd capacitor between the blue terminal of the coil and ground.

Connect a length of hookup wire from terminal 3 (the terminal toward the rear) of the 50k-ohm potentiometer and terminal C4. Solder the lead to the potentiometer terminal.

Connect a 150k-ohm resistor between terminals A2 and B2. Solder A2.

Solder a length of hookup wire from terminal B2 to the center terminal of the 50k-ohm potentiometer.

Before you connect any leads to the rf transformer, be sure to remove all wax from the terminals. If any wax remains on the terminals it will be impossible to make a solder connection.

Connect a short length of hookup wire from the blue terminal of the rf transformer (TR31) to the nearer terminal of the trimmer capacitor. Connect a length of wire between the red transformer terminal and the free terminal of the capacitor. Solder both capacitor terminals carefully. Make sure all of the blades are soldered at each terminal.

Solder a 470-pf disc capacitor across the terminals of the trimmer capacitor.

Solder a length of hookup wire from lug 3 of EC25 to the blue terminal of the rf transformer.

Connect a length of wire between the red and black terminals of the rf transformer. Solder the red terminal.

Solder a length of hookup wire from the black terminal of the rf transformer to terminal C4.

Solder the anode lead of a signal diode to the green terminal of the rf transformer. Solder about a 2-inch length of wire to the cathode lead and connect the end of the wire to terminal C3.

Solder a .05-mfd capacitor and a 15k-ohm resistor in parallel between terminals C3 and B7.

Check your wiring with the schematic and be sure all connections are soldered.

Step 1: To adjust the modulator circuit.

Slip the test clip on the probe of the tvom and clip it to the green terminal of the rf transformer. Clip the ground lead to the chassis. Set the tvom to measure ac voltage on the 12V range. The polarity switch should be in the normal position.

Set the oscillator frequency selector to 70 on the dial scale, turn the 50k-ohm potentiometer fully counterclockwise, and energize the circuit. Adjust the trimmer capacitor fully clockwise. While observing the meter, turn the adjusting screw in the trimmer capacitor slowly counterclockwise. The reading should rise to a peak and then begin to fall. Set the trimmer for the voltage peak near the fully clockwise position. Readjust the frequency control to 50 on the dial. Use this frequency throughout the experiment.

Move the tvom probe to terminal C3 and measure the ac voltage at the output of the diode detector. Vary the 50k-ohm potentiometer, which is the modulation level control, and note the variation in the ac voltage. If necessary, switch the tvom to a lower range.

Step 2: To show amplitude modulation.

Turn the modulation control fully counterclockwise. Connect your tvom to measure the ac voltage between the green terminal of the rf transformer and ground. The tvom will indicate the unmodulated rf carrier voltage across the transformer winding. Record your reading in the first column in Fig. 58-5.

Turn the modulation control fully clockwise, then disable the rf oscillator by shorting lugs 11 and 12 of EC25 together. This will stop the oscillator. Again measure the ac voltage across the winding with modulation applied and with the oscillator stopped. Record your reading in the second column of Fig. 58-5. When you have recorded your results remove the short from the oscillator circuit.

With the modulation control still set fully clockwise and the oscillator operating, measure the amplitude modulated voltage across the transformer secondary winding. Record this value in the last column of Fig. 58-5.

Step 3: To show diode detection.

Move the tvom probe to terminal C3. Your meter now reads the voltage across the diode detector load consisting of the 15k-ohm resistor and the .05 mfd capacitor.

(A) Turn the modulation control to minimum (fully counterclockwise) and measure and record the ac voltage in the first column for Step 3A Fig. 58-5. Adjust the modulation control to maximum and short lugs 11 and 12 together. Read the ac voltage and record it in the second column of Fig. 58-5. Finally, measure and record the ac voltage with the rf carrier amplitude modulated. Turn the circuit off.

(B) With the tvom probe still connected to terminal C3, switch the tvom to read positive dc voltage on the 3V range.

Turn the circuit on, turn the modulation control fully counterclockwise, and measure the dc voltage with the rf carrier only. Record the reading in the first column of Fig. 58-5 for Step 3B. Similarly, measure and record the dc voltage with the rf oscillator shorted out and modulation applied, and with the rf

STEP	VOLTAGE MEASUREMENT	RF ONLY	60 Hz ONLY	MODULATION
2	AC across secondary			
3A	AC at detector			
3B	DC at detector			

Fig. 58-5. Use this chart for Steps 2 and 3.

oscillator fully modulated. Turn the circuit off.

Step 4: To see the effects of removing the .05 mfd rf filter from the detector load.

Unsolder the lead of the .05 mfd capacitor from terminal C3. Energize the circuit and measure the dc voltage as you vary the modulation control. You should see some small variation.

Switch the tvom to read ac voltage. Observe the ac voltage across the 15k-ohm resistor as you vary the modulation. Note that when you turn the modulation control to minimum, the voltage does not go to zero. Turn the circuit off.

Discussion: An amplitude modulated signal consists of a carrier frequency signal which has intelligence in the amplitude variations. The carrier alone contains no useful information. It must be modulated or changed in some way.

In Step 2, you found that the rf carrier by itself produced an ac voltage across the secondary of the rf transformer. This voltage is proportional to the strength (level) of the carrier. The voltage is present only when the rf oscillator is operating. This is because the 60 Hz modulating frequency is too low in frequency to pass through the resonant circuit in the collector circuit of Q_2.

You should have found in Step 3 that there is an ac voltage at the detector output which varies with the modulation. This is the detected or demodulated 60 Hz ac voltage which was used to modulate the rf carrier. You also found that the detector produced a dc voltage which varied with the strength of the carrier signal.

A diode detector is a half wave rectifier and filter circuit very similar to the circuit you used in your power supply experiments. The diode passes only the positive portion of each cycle of rf, thus causing current flow up through the 15k-ohm load resistor. The .05 mfd capacitor filtered out the pulses of rf voltage, leaving only the low modulating frequency at the output. With the capacitor removed you should have observed that even with no modulation present there was still an ac voltage developed across the 15k-ohm load resistor.

Instructions for Statement 58: For this Report Statement you will simulate a defective detector diode and determine how it affects the detector output signal.

Solder a short length of wire across the leads of the diode between terminal C3 and the green terminal of the rf transformer. Reconnect the lead of the .05 mfd capacitor to terminal C3.

Energize the circuit and measure the ac and dc voltages across the 15k-ohm resistor and .05 mfd capacitor with the modulation control fully counterclockwise and fully clockwise. This should give you enough information to answer the statement.

Turn the equipment off and answer the Statement here and on your answer sheet.

Statement No. 58: When the diode was shorted, the detector circuit:

(1) worked normally.

[✓ *(2)*] *produced no output.*

(3) produced a high negative dc voltage.

The FM Detector

In your regular lessons you have learned that there are several types of FM detectors in wide use. Two of the more common types in FM receivers are the phase detector, commonly known as the discriminator, and the ratio detector.

When the discriminator is used, it is always preceded by a limiter stage. The purpose of the limiter stage is to eliminate variations in the carrier amplitude caused by static or other electrical noise. The FM signal fed to the discriminator therefore has a constant amplitude.

The ratio detector does not need a limiter stage because, under ordinary conditions, it is unaffected by variations in carrier strength. In this case, the detector can be preceded by an i-f amplifier. You may find in some receivers that a limiter stage is used with a ratio detector. The limiter is added to make certain that no noise pulses get through to the output.

In the next experiment you will study the phase detector or discriminator. Later you will study the ratio detector.

Although the principles of FM operation have been covered thoroughly in your regular lessons, we will review the detector action here. Let us see how a discriminator demodulates an FM signal by studying the basic Foster-Seeley Discriminator shown in Fig. 13.

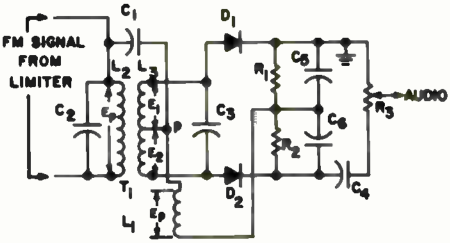


Fig. 13. Basic Foster-Seeley discriminator circuit.

The discriminator transformer, T_1, is of special design. Its primary winding, L_2, is tuned to the resting frequency by C_2, and its center-tapped secondary winding, L_3, is tuned to the same frequency by C_3. The current flowing through L_2 induces a corresponding FM voltage in L_3, and produces across the two sections of L_3 voltages E_1 and E_2, which are always equal in magnitude and 180° out-of-phase with each other.

At the same time, the primary voltage E_p is applied through C_1 to choke coil L_1. Since the reactance of C_1 is small, the voltage across L_1 is very nearly equal to E_p.

The limiter output voltage E_p (across L_1) in series with E_1 is applied to diode 1. Likewise, the limiter output voltage E_p in series with E_2 is applied to diode 2. These voltages are not in-phase: E_1 and E_2 are 180° out-of-phase with each other, and each is out-of-phase with E_p. The net voltage applied to each diode section is, therefore, the vector sum of the two individual voltages acting on that section.

Each diode rectifies its net applied rf voltage, and produces a proportional dc output voltage across its load resistor. The load resistor for diode 1 is R_1, and that for diode 2 is R_2. Electrons flow in opposite directions through R_1 and R_2, as you can easily see by tracing the diode circuits. This means that the combined voltage across R_1 and R_2, which is the output voltage of the discriminator, at any instant is equal to the difference between the individual voltages across these resistors. If the individual voltages are equal, the discriminator output voltage will be zero. If the voltages across R_1 and R_2 are different, the combined voltage will have the polarity of the larger of the two individual voltages, and will be equal in magnitude to their numerical difference.

Now let us consider the factors that make the output voltage of one diode higher than that of the other. First of all, we must choose some reference voltage or current. Since E_p is common to all circuits under study, we can use it as our reference voltage.

Phase relationships in this discriminator circuit must be considered for three different conditions: 1) when the signal frequency is equal to the frequency to which the discriminator resonant circuits are tuned; 2) when the signal frequency is lower than the resonant frequency; 3) when the signal frequency is higher than the resonant frequency. The vector diagrams for these three conditions are shown in sketches A, B, and C, respectively, of Fig. 14, with primary voltage E_p serving as the reference vector in each case. The rf voltage E_s that is induced in secondary winding L_3 is 180° out-of-phase with the primary rf voltage E_p, so it is shown 180° out-of-phase with reference vector E_p in each of the vector diagrams.

When the signal is exactly at the i-f resting value to which the discriminator circuits are tuned (in other words, when no sound is being transmitted), the secondary tuned circuit L_3-C_3 is at resonance, and the secondary current, I_s, flowing through L_3 is in phase with E_s, as indicated in sketch A of Fig. 14. When this current flows through the inductance L_3, the voltage produced across this inductance must lead the current by 90°. The coil ends must always be 180° out-of-phase (when one end is positive, the other is negative). Therefore, if we assume that voltage E_1 leads I_s by 90°, then E_2 must lag 90° behind I_s. This makes E_1 and E_2 each 90° out-of-phase with E_p, because E_p is 180° out-of-phase with I_s.

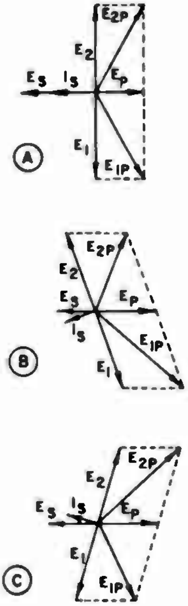


Fig. 14. Phase relationships in the discriminator circuit. (A), when signal is at resonant frequency; (B), when signal frequency is below resonant frequency; (C), when signal frequency is above resonant frequency.

Adding E_p and E_2 vectorially gives E_{2p} as the resultant voltage acting upon diode 2. Likewise, adding E_p and E_1 vectorially gives E_{1p} as the resultant voltage acting upon diode 1. The vector diagram in sketch A shows these two voltages E_{1p} and E_{2p} for the no-modulation condition; therefore, the dc voltages developed across R_1 and R_2 by the two diodes are equal in magnitude and their sum is zero. This is just as it should be, since no audio signal should be obtained when there is no modulation at the transmitter.

When the frequency of the signal is lower than the i-f resting frequency to which resonant circuit L_3-C_3 is tuned, the circuit becomes capacitive, and I_s leads E_s as shown in Fig. 14B. Since voltages E_1 and E_2 must be 90° out-of-phase with I_s, the resultant voltages (E_{2p} and E_{1p}) are unequal, with E_{1p} (the voltage applied to diode 1) the larger. Referring to Fig. 13, you can see that with diode 1 getting the higher rf voltage, there is a higher dc voltage across R_1 than across R_2. The combined voltage across R_1 and R_2 is, therefore, negative with respect to ground. The more the signal frequency swings below the i-f resting frequency, the greater the negative voltage applied to the audio amplifier input.

By a similar analysis we can get the vector diagram shown in Fig. 14C, in which the signal frequency is higher than the resonant frequency. When this occurs, the net voltage applied to the input of the af amplifier (the sum of the drops across R_1 and R_2) is positive with respect to ground.

Thus the frequency discriminator circuit shown in Fig. 13 produces a dc voltage that is proportional to the deviation between the incoming signal frequency and its resting value. Its polarity is determined by the direction of this frequency deviation. In this way the discriminator converts an FM signal directly into a replica of the original audio signal voltage that was used to modulate the FM transmitter.

RF bypass capacitors C_5 and C_6 in Fig. 13 must have a low reactance at the i-f resting frequency, and yet must have a high reactance at audio frequencies so that there will be no serious shunting effect upon the af voltage developed across R_1 and R_2.

The relationship between the incoming rf signal frequency of an FM receiver and the dc output voltage of a discriminator is shown in Fig. 15. At the resting frequency, the dc voltage across the discriminator load resistors is zero when the circuit is properly adjusted. When the frequency is above or below the resting frequency, a dc voltage that is equal to the difference between the voltages across the individual load resistors appears across the combined load. This voltage may be either + or − with respect to the zero level at the resting frequency. A discriminator set up like the one we just described has the response shown in Fig. 15, in which frequencies below resonance produce positive output voltages. This curve is commonly known as an "S" curve.

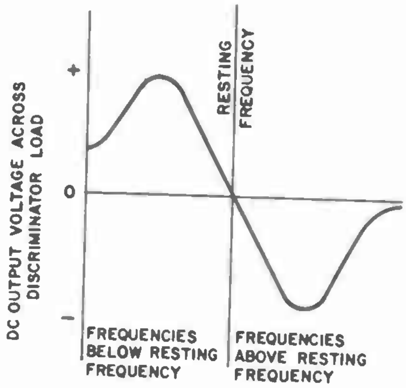


Fig. 15. Typical S response curve for a discriminator circuit.

EXPERIMENT 59

Purpose: To show that in an FM discriminator the amplitude and polarity of the dc output voltage depend upon the frequency deviations of the incoming signal; and

To show that unless this circuit is preceded by a limiter stage, variations in the amplitude of the rf carrier will affect the dc output.

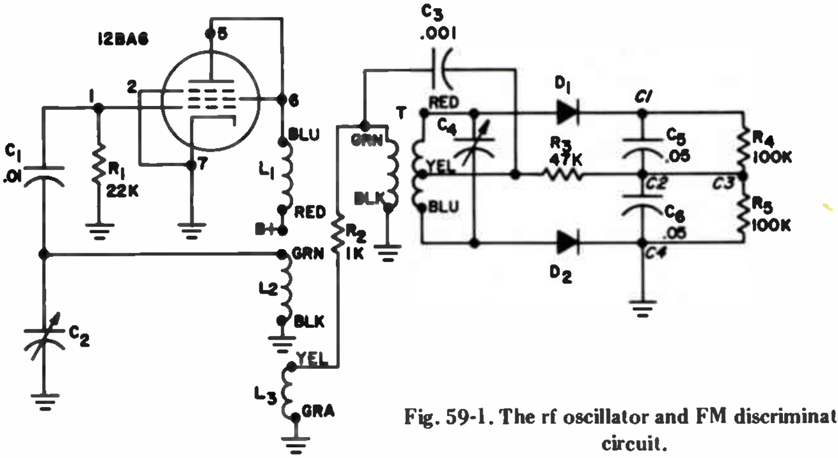


Fig. 59-1. The rf oscillator and FM discriminator circuit.

In proving that a phase discriminator will demodulate an FM signal, you will use the circuit shown in Fig. 59-1. As you can see, it is essentially the same as the basic circuit in Fig. 13. Although we have substituted a resistor for the series inductance L_1 in Fig. 13, the circuit action is the same as that described for the basic circuit.

In normal operation, the audio modulating voltage changes the frequency of the rf carrier so rapidly that the S-curve characteristic can be observed only with an oscilloscope.

However, if we manually adjust the frequency of the rf oscillator to different values above and below an assumed resting frequency, we can measure the dc output voltage for each frequency and plot the S curve.

As shown in Fig. 15, the polarity of the dc voltage across the discriminator load depends on whether the incoming rf signal is above or below the resting frequency. If an ordinary voltmeter is used to indicate the dc output, the polarity of the test leads must be changed when the voltage changes polarity. To avoid this troublesome procedure, servicemen use a voltmeter that has its zero at the center of the scale. Negative voltages swing the meter pointer to the left of zero and positive voltages swing it to the right of zero. There is no need to change the polarity of the test leads to make a reading.

The tvom which you are using in your practical training course can be adjusted so that the zero voltage pointer position is at the center of the scale. When this is done, of course, each range is effectively cut in half. For example, on the 12-volt range you can measure positive or negative 6 volts. When you are instructed to do so, set the tvom to center zero by rotating the zero control and take your readings on the lower two scales. As you perform the steps in the experiment, you may take readings on any range that seems convenient. The important thing is that you take all your readings on the same range.

Experimental Procedure: In order to perform this experiment you will need your tvom, the experimental chassis with the parts on it and the following:

1 1k-ohm resistor
1 22k-ohm resistor

1	47k-ohm resistor
2	100k-ohm resistors
1	.001 mfd disc capacitor
1	.01 mfd disc capacitor
2	.05 mfd disc capacitors
1	12BA6 tube
2	Signal diodes

Some of these parts will be removed from circuits which you used earlier.

First dismantle the circuit wired on the chassis. Unsolder and remove all parts and leads connected to the rf transformer except the leads connecting the blue and red terminals to the trimmer capacitor. Disconnect the leads and parts from the 50k-ohm potentiometer, the oscillator coil, and the 4-lug terminal strip, strip C. Also, remove the leads and the parts connected to all lugs except lugs 4 and 5 on circuit board EC25. Unsolder the tuning capacitor lead from lug 1 of EC25 and connect it to the green terminal of the oscillator coil.

Loosen the screw at hole U and turn the 4-lug terminal strip around so that terminal C1 is toward the rear of the chassis.

Construct the circuit shown in the schematic in Fig. 59-1. Coils L_1, L_2, and L_3 are windings of the oscillator coil mounted at the front of the chassis. The transformer connected to the diodes is the rf transformer. To wire the circuit, proceed as follows:

Connect a length of wire from lug 6 to lug 8 on EC25. Solder lug 8. Solder a length of hookup wire from lug 6 to terminal B1.

Connect a length of wire from the foil connected to pin 6 of the tube socket to lug 9. Solder a length of wire from lug 9 to the blue terminal of the oscillator coil at the front of the chassis.

Connect a 22k-ohm resistor from lug 7 to terminal B7. Solder a .01 mfd capacitor to lug 7. Solder a short length of wire between the free lead of the capacitor and the green terminal of the oscillator coil.

Solder a length of wire from the black terminal of the oscillator coil to ground. Connect a short length of wire from the gray terminal of the oscillator coil to ground. Solder a length of wire from the red terminal of the oscillator coil to terminal A6.

Solder a 1k-ohm resistor to the yellow terminal of the oscillator coil. Solder a piece of hookup wire to the free lead of the resistor and connect the other end of the wire to the green terminal of the rf transformer.

Connect a .001 mfd capacitor between the green and yellow terminals of the rf transformer. Connect the black terminal of the rf transformer to ground, using a short length of wire.

Connect a 47k-ohm resistor between the yellow rf transformer terminal and terminal C2.

Connect a 100k-ohm resistor between terminals C1 and C3. Connect another 100k-ohm resistor between terminals C3 and C4.

Connect a .05 mfd capacitor between terminals C1 and C2. Connect a .05 mfd capacitor between terminals C2 and C4. Solder a piece of wire between terminals C2 and C3.

Connect a signal diode between the red rf transformer terminal and terminal C1, with the cathode lead to terminal C1. Connect a second signal diode between the blue transformer terminal and terminal C4, with the cathode lead to C4. (Use lengths of wire to extend the diode leads.)

Insert the 12BA6 tube in the socket on EC25.

When you complete the wiring, check your work against the schematic diagram. Look for short circuits between the B+ circuit and ground and around the lugs on the circuit board. Also look for poor connections.

To test the oscillator circuit, turn the circuit on and measure the negative grid leak bias voltage across the 22k-ohm resistor in the grid circuit. You should read a negative voltage of 25 volts or more. The presence of grid leak bias is a good indication that the circuit is oscillating.

Step 1: To make the preliminary adjustment of the discriminator circuit.

Set your tvom to measure dc voltage on the 12V range. The polarity switch should be set to reverse, as you will be measuring a negative voltage.

Turn the adjusting screw on the trimmer capacitor fully clockwise for maximum capacity. Clip the tvom ground lead to the chassis. Slip the test clip on the tvom probe and clip the probe to terminal C2.

Set the tuning capacitor to 50 on the dial scale and energize the circuit. Adjust the trimmer capacitor for maximum negative voltage on the meter. If necessary, switch to a higher range to keep the meter from going off scale. Set the trimmer capacitor for the highest negative voltage.

Step 2: To complete the adjustment of the discriminator circuit.

Disconnect the probe from the circuit and return the polarity switch to "normal." Adjust the zero adjust control for center scale zero. The tvom should be set to the 12V range. Clip the probe to terminal C1 and turn the circuit on. Observe the meter carefully. If it does not indicate exactly zero (center scale), readjust the trimmer capacitor slightly until you read zero on the meter. This adjustment is critical so make it very carefully.

Step 3: To show that frequency variations in the incoming signal will cause a variation in the dc output voltage.

Leave your meter connected from terminal C1 to the chassis, and vary the frequency of the incoming signal by varying the setting of the tuning capacitor. Note that when you move the pointer to the right of 50, the meter pointer will go in one direction; when you move the pointer to the left, it will go in the other direction. This shows that the discriminator responds to frequency variations.

Step 4: To show that the polarity of the dc output voltage depends upon whether the frequency deviation of the

RF OSCILLATOR DIAL SETTING	OUTPUT VOLTAGE
0	+
10	+
20	+
30	+
40	+
50	0
60	–
70	–
80	–
90	–
100	–

Fig. 59-2. Record your readings for Experiment 59 here.

carrier is above or below the resting frequency of the carrier.

Reset the rf oscillator frequency control to 50 on the scale, and check to make sure that the meter pointer has not moved to the right or to the left of the center zero position. If it has, bring it back by carefully adjusting the trimmer capacitor.

Set the tuning capacitor to 0 (maximum capacity), and read the meter on the ±6V (12V) scale. Record your reading in Fig. 59-2.

Set the tuning capacitor to each of the dial settings listed in Fig. 59-2, read the meter on the 12V scale for each setting, and record your readings in Fig. 59-2. At 50 the meter pointer should be at center scale, indicating 0 volts. Meter deflections to the right indicate positive polarity; meter deflections to the left indicate negative polarity.

Step 5: To plot your results on the graph in Fig. 59-3.

Oscillator dial settings below 50 on the scale should have produced positive voltages and caused meter pointer deflections to the right of the center zero position. Oscillator dial settings above 50 should give negative voltage readings, causing deflection to the left of the center zero position. Plot the point for the voltage reading for each setting of the dial. Then connect them by drawing a smooth line through the points.

When you have your curve completed, compare it to the curve shown in Fig. 15. Your curve should have a similar shape. It probably won't be as symmetrical as this, but it should be approximately S-shaped.

Step 6: To show that variations in the amplitude of the rf carrier affect the output of the discriminator.

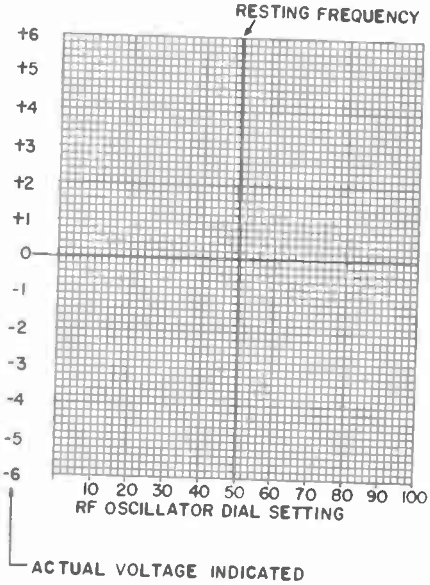


Fig. 59-3. Plot readings for Exp. 59 here.

Adjust the tuning capacitor to some point above or below the resting frequency at which an appreciable meter deflection is obtained, and change the rf input by momentarily shorting the green terminal at the rf transformer, TR31, to the chassis with a screwdriver blade. When this is done, the output of the discriminator should vary. Turn your equipment off.

Discussion: You have shown that changing the frequency of the rf carrier signal applied to a discriminator changes the amplitude of the dc output voltage. Thus, in an FM receiver the dc voltage at the output of the discriminator corresponds to the original signal used to frequency-modulate the carrier. This shows that the discriminator detects, or demodulates, the signal. As you vary the oscillator frequency through resonance with the tuning capacitor, output also varies. The output curve you plot should have nearly an S shape.

Under ideal conditions the S curve will be symmetrical above and below the zero voltage axis of the graph. However, in a practical circuit it is unlikely that the curve will be symmetrical. The circuit may not be balanced due to unequal capacities to ground, variations in the tubes, etc.

In the last step you showed that amplitude variations also affect the dc output. This effect is undesirable in an FM receiver. In an actual receiver a limiter stage is used to remove the amplitude variations, so that the signal applied to the discriminator is of a constant amplitude. In a ratio detector, amplitude variations in the carrier caused by noise or static have very little effect on the output. Thus, a limiter stage is ordinarily not necessary. You will work with a ratio detector in the next experiment.

Instructions for Statement 59: For your report on this experiment you are to find out what will happen when one of the diodes become defective.

Connect the tvom to measure the dc voltage between terminal C1 and the chassis, with the probe connected to C1. Adjust the tuning capacitor so that the voltage is at zero center between the two peaks.

Now disconnect the diode lead from the blue terminal of the rf transformer. Again measure the voltage between C1 and the chassis, and see if the voltage between these points is still zero. Answer the Statement here and on the Report Sheet. Reconnect the diode lead to the blue terminal of the rf transformer.

Statement No. 59: When I disconnected the diode lead to simulate a defective diode, I found that the voltage between the chassis and C1 was:

(1) still at zero.
[✓ *(2) no longer at zero.*]

EXPERIMENT 60

Purpose: To show that a ratio detector will demodulate an FM signal, and that its characteristic has an S shape similar to that of a phase discriminator.

Introductory Discussion: As you learned in the last experiment, the phase discriminator can respond to variations in the amplitude of the input signal, and it will respond to noise signals as well as to the desired FM signal. This response can be overcome by adding a limiter stage between the last i-f amplifier and the FM detector. Many FM receivers, however, use a detector circuit that is in itself relatively insensitive to variations in the amplitude of the rf carrier.

One of these amplitude-insensitive detectors is the "ratio" detector shown in Fig. 60-1. As you can see, it is similar to the discriminator you built in the last experiment, except that one diode is reversed, capacitor C_4 is added, and a change is made in the output connections. As in the phase discriminator,

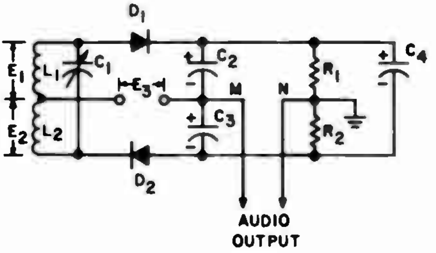


Fig. 60-1. Ratio detector circuit for Exp. 60.

voltages E_1 and E_2 are 180° out-of-phase, and voltage E_3 is 90° out-of-phase with the voltages across L_1 and L_2 when the rf voltage at the input is unmodulated.

As long as the input i-f signal remains at the frequency that corresponds to the center resting frequency of the FM signal, the voltage $E_1 + E_3$ is equal to the voltage $E_2 + E_3$, so the rectified dc voltage across capacitor C_2 is equal to that across capacitor C_3. Since one of the diodes (D_2) is reversed from the connection used in a phase discriminator, the dc voltage across capacitor C_2 and C_3 is the sum of the two voltages rather than the difference. This voltage is across the load resistors R_1 and R_2 and is also applied to capacitor C_4.

The audio output of the stage is developed between points M and N. When the voltages across capacitors C_2 and C_3 are equal, the dc voltage is the same at M as at N. Thus, the audio output, as seen in Fig. 60-2A, is zero when the received signal is at the resting frequency.

Let us suppose we have a voltage of 5 volts each across capacitors C_2 and C_3 in Fig. 60-2A. This makes the total voltage across capacitor C_4 10 volts. Since the value of this capacitor is rather large, it holds its charge for an appreciable time even when the input changes.

Suppose that the frequency of the input i-f signal changes so that the voltage across C_2 increases to 8 volts; the voltage across C_3 decreases to 2 volts. This is shown in Fig. 60-2B. The sum is still 10 volts; and the sum voltage divides equally across the equal value resistors R_1 and R_2. This means that the voltage at M will be 3 volts negative with respect to N. Similarly, if the input frequency should deviate the same amount in the other direction, the voltage across C_2 will decrease to 2 volts, and that across C_3 will increase to 8 volts. As shown in Fig. 60-2C, M will then be 3 volts positive with respect to N.

The action so far is the same as that of the usual phase discriminator circuit. However, the presence of capacitor C_4 makes a difference because it minimizes the effect of amplitude variations in the input. Let us see how.

Capacitor C_4 is charged so that the average voltage across it is proportional to the FM signal strength. Since the capacitor is large, generally 5-mfd to 20-mfd, the time-constant of the circuit consisting of C_4, R_1, and R_2 is about 0.1 to 0.4 second. This means that C_4 is slow in responding to variations in the amplitude of the input signal. If the input signal increases or decreases suddenly, the capacitor voltage is not able to follow the variations. The dc voltage across C_4 can, however, follow slow variations in the amplitude of the input signal.

Let us assume, for example, that a certain value of frequency deviation pro-

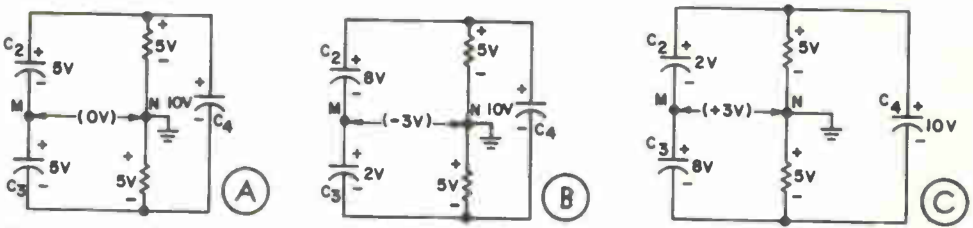


Fig. 60-2. The dc output voltage of a ratio detector is the difference between the voltages of points M and N.

duces an 8-volt drop across C_2, and 2 volts across C_3, as shown in Fig. 60-2B. The output voltage will be −3 volts. Now assume that for some reason, say a burst of static or an interfering station, the amplitudes of voltages E_1, E_2, and E_3 all increase equally. The voltages across capacitors C_2 and C_3 will both try to increase. However, since they must always be equal to that across C_4, which cannot change quickly, the voltages across C_2 and C_3 will remain constant despite the sudden increase in input voltage. The extra voltage will be dropped across D_1 and D_2 because more current will flow through them as they attempt to increase the charge on C_4.

Experimental Procedure: For this experiment you need the setup from the last experiment, plus:

1 .01-mfd capacitor
1 6-mfd electrolytic capacitor

Wire the circuit as shown in Fig. 60-3. Only a few changes are necessary to convert your phase discriminator into a ratio detector. First, reverse the connections to diode D_1 so that the cathode is connected to the red terminal at the rf transformer and the anode is connected to terminal C1. Second, separate the junction of R_4 and R_5 from the junction of capacitors C_5 and C_6. To do this, remove the piece of bare wire you connected between terminals C2 and C3. You will measure a dc voltage between these points to get the necessary data for drawing an S curve. Finally, connect a 6-mfd electrolytic capacitor between terminals C1 and C4. Make sure you observe the polarity of the capacitor; connect the positive lead to terminal C4, as shown in the diagram. Check your work carefully.

Step 1: Adjust the ratio detector circuit.

The adjustment of this circuit is essentially the same as for the phase discriminator, except that the connections for dc output voltages are different. Adjust your tvom for center scale zero as in the last experiment. Connect the ground clip at the junction of resistors R_4 and R_5, terminal C3, and the probe at the junction of capacitors C_5 and C_6, at terminal C2. The tvom should be set to

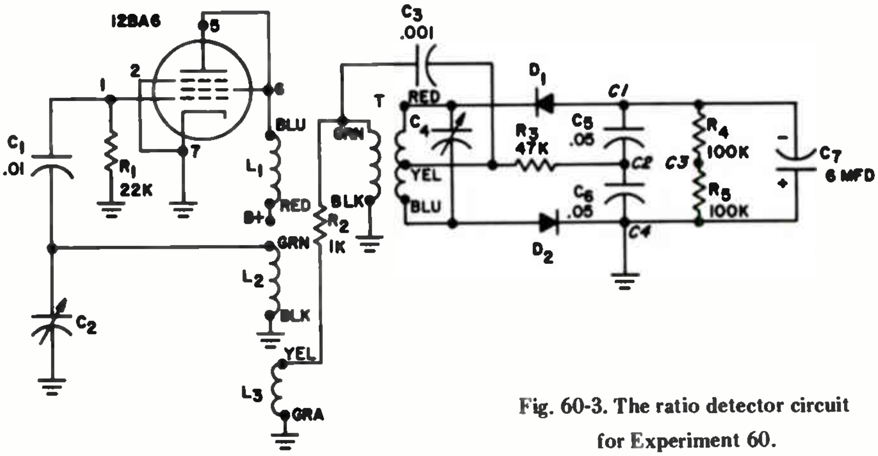


Fig. 60-3. The ratio detector circuit for Experiment 60.

"normal." Apply power to the circuit. Now, set the tuning capacitor to 50 and adjust the trimmer capacitor for the zero-center reading between the two peaks.

Step 2: To show that a ratio detector will demodulate an FM signal.

Apply power and tune the tuning capacitor to either side of the resting frequency as you did in the previous experiment, noting that the dc output voltage changes as the input signal varies in frequency.

Step 3: To show that a ratio detector has an S-shaped dc output characteristic.

With the tvom connected as described in Step 1, turn the range selector switch to 12V, and measure the dc output of the ratio detector. You will not make measurements over the entire frequency range, only enough to show the S-shaped characteristic.

RF OSCILLATOR DIAL SETTING	OUTPUT VOLTAGE
30	+
35	+
40	+
45	+
50	0
55	–
60	–
65	–
70	–

Fig. 60-4. Record readings for Exp. 60 here.

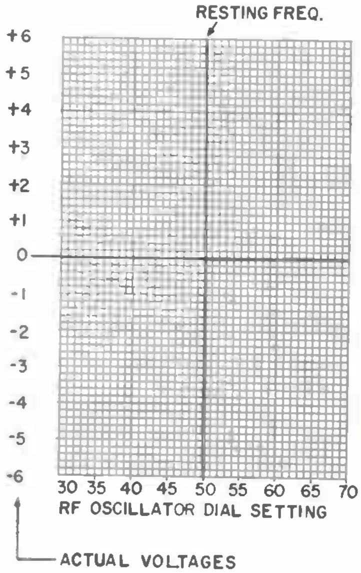


Fig. 60-5. Plot results for Exp. 60 here.

Starting with the tuning capacitor, set at 30, take the readings of the dc output at each of the settings listed in Fig. 60-4. Record your readings in Fig. 60-4. Notice that the readings for dial settings below 50 should make the meter pointer move to the right. Frequencies higher than the resting frequency should make the meter pointer move to the left.

Plot your results in Fig. 60-5. The curve should be S-shaped.

Discussion: Again as in the previous experiment, the S curve is small because of the limited rf input voltage. We can increase the rf input by reducing the value of R_2, but doing so will decrease the degree of isolation between L_3 and the rf transformer. If the rf transformer is not sufficiently decoupled from L_3, any adjustment of capacitor C_4 will tend to change the frequency of the rf oscillator.

A ratio detector is properly tuned when the secondary of the rf transformer is set for zero dc output at the i-f resting frequency. In some ratio-detector circuits a single resistor is used in place of R_4 and R_5. In order to check a circuit of this type for proper tuning, you will have to add a series combination of two resistors of equal value in parallel with this single resistor. This will give you a point to which you can connect a dc voltmeter.

Instructions for Statement 60: For your report on this experiment you are to determine how the capacity of the stabilizing capacitor C_7 affects the dc voltage across resistors R_4 and R_5 when the amplitude of the input is varied rapidly.

Solder a short length of hookup wire to the yellow terminal of the rf oscillator coil. Arrange the free end of this lead so that you can tap it against the chassis two or three times a second, thereby varying the rf input rapidly between its normal value and zero. Readjust the Zero control so that the meter pointer is at 0 on the left side of the meter scale. Connect the ground lead of the tvom to the chassis and connect the probe to terminal C1. Set the polarity switch to reverse.

After making sure that the ratio detector is properly adjusted, measure the dc voltage across capacitor C_7. Now vary the amplitude of the rf carrier by tapping the lead you soldered to the yellow terminal at the oscillator coil against the chassis. Watch the meter when you do this. There should be very little if any change in the meter reading.

Now, disconnect the 6-mfd capacitor C_7, and connect a .01-mfd capacitor in its place. Check the dc voltage across this capacitor, repeat the grounding procedure to simulate a varying rf amplitude, and watch the meter. Turn your equipment off and indicate the results of this test in the Statement for this experiment.

Statement No. 60: When I decreased the capacity of capacitor C_7 to .01-mfd, and then rapidly changed the amplitude of the rf signal, the dc voltage across the .01-mfd capacitor:

(1) remained unchanged.
[✓ *(2) varied appreciably.*]

A REVIEW

This completes your demonstrations of basic circuit actions; you will go on to service techniques in your next kit. Let us review what you have learned.

First of all, you have learned how to solder, a technique all radio and television technicians must master. You should now be able to use just the right amount of solder to make good electrical connections. Also, you should have formed the habit of checking your soldering iron tip frequently, and filing and retinning it when necessary.

By assembling and dismantling circuit after circuit, you have learned how to handle many kinds of electronic parts. Perhaps you learned the hard way that resistor and capacitor leads may break after being bent back and forth several times, and that you must be careful when you work with them.

Your work of assembling and tracing circuits undoubtedly speeded up after you learned to identify resistor values by the color code and after you became adept at handling your pliers, cutters, hookup wire, and the NRI tvom. You no longer should find it necessary to puzzle over the connections for any kind of measurement the instrument will make. The correct procedures should now come to you naturally.

Another important accomplishment you have gained is the ability to assemble a circuit without the aid of a pictorial diagram. You now know that there are many different ways in which a circuit can be assembled and still correspond electrically to a schematic.

Your work with rf circuits taught you the important technique of tuning circuits to resonance at a given frequency so as to produce a maximum output voltage. You will use this every time you align a radio or TV set.

If there is any question in your mind concerning your ability in any one of the techniques we have listed here, concentrate on that particular technique. For example; if you still find it difficult to use a schematic diagram to locate parts, get an old receiver and the circuit diagram for it and practice tracing out the circuit. It is still not too late to master the technique of tuning resonant circuits, of tracing circuits, or of soldering.

These are only a few of the many practical things you have learned as you demonstrated fundamental circuit actions ranging from Ohm's Law to the theory and practice of frequency modulation.

LOOKING AHEAD

In your next kit you will build an ac-dc receiver, complete with a PM speaker and an efficient ferrite loop antenna. You will get a special chassis on which to assemble the set, and a 2-gang tuning capacitor. When you have the receiver assembled, you will carry out complete voltage measurements and make point-to-point resistance tests on it. Then you will align it for normal operation within the standard broadcast band.

The ten experiments in the next kit have been designed to give you practical experience in recognizing the symptoms of common defects in general radio service work. This experience, plus the training you have already had, will give you the background you need to qualify as a real expert.

You will probably want to do some experimenting on your own using the parts left over from the experiments. If so, you will want to put your audio oscillator back into operation and you will want to build an rf oscillator.

Audio Frequency Oscillator. The oscillator which you used in the early part of this kit is complete except for the 1k-ohm stability control. Reinstall the potentiometer on the board and wire it in as shown in the schematic diagram in Fig. 6. To use the oscillator, connect 12V to 20V dc between the ground foil and square 5F and take the output signal between square 1E and ground.

When you need a 1k-ohm potentiometer in the experiments in the future kits, you will have to remove the potentiometer from your oscillator.

RF Oscillator. The schematic diagram of an oscillator which you can build from your available parts is shown in Fig. 16. This is a Clapp oscillator and, as you can see, it is very similar to the Colpitts oscillator which you used in experiments 56 through 58. You should still have circuit board EC25, the oscillator coil and the tuning capacitor mounted on the

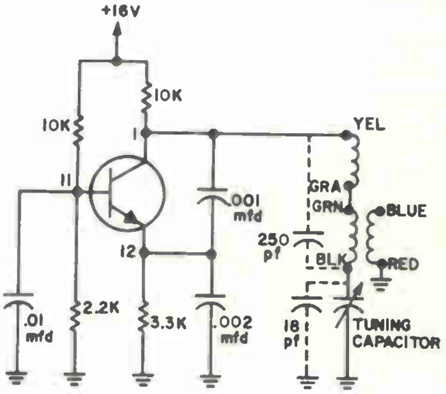


Fig. 16. Schematic of rf oscillator circuit.

chassis. Therefore you will find the circuit easy to wire. Wire the oscillator from the schematic. For the present, do not connect the 250 pf and 18 pf capacitors. The connections to the transistor are made to lugs 1, 11, and 12, and the operating voltage is supplied by the low voltage power supply on circuit board EC24.

Remove all other parts from the chassis and clean their leads and terminals. Put the parts in a safe place as you may need them for carrying out future experiments.

To test the oscillator, you can measure the ac voltage across the secondary (red/blue) winding of the oscillator coil. You should read up to 1V ac as you vary the oscillator frequency. A more reliable way to test the oscillator is to tune an AM receiver to a station at about the center of the dial and see if your oscillator can produce interference. Solder about a 3 ft length of hookup wire to the yellow terminal of the oscillator coil and bring the end near the receiver. Tune your oscillator throughout its range while listening to the radio. You should be able to hear the interference.

Refer to the schematic in Fig. 16 to see how the oscillator works. The transistor is operated in the common base configuration, with the input applied to the emitter and the output taken off at the collector. The feedback necessary to sustain oscillations is coupled through the capacitive voltage divider from the collector to the emitter. Collector voltage is provided through the 10k-ohm load resistor.

The frequency of oscillation is determined by the network made up of the series-connected coils, the tuning capacitor and the capacitive voltage divider. The tuning capacitor, being in series with the two coils, varies the effective or net inductance of the coils. This net inductance, in turn, resonates with the total capacitance of the capacitors in the voltage divider. The oscillator frequency is approximately equal to the resonant frequency of this circuit.

The frequency range of the basic oscillator circuit is from about 570 kHz to about 1650 kHz, which nearly covers the AM broadcast band. The frequency range can be lowered to include the AM receiver intermediate frequency by connecting the 250 pf and 18 pf capacitors as shown in Fig. 16. The lower range is approximately 410 to 540 kHz.

You can determine the oscillator frequency by "zero beating" its output with known radio frequencies such as the carrier frequencies of AM radio stations. Tune in a station on the radio and adjust the oscillator until you hear a squeal in the audio. What you hear is the difference frequency between the radio station carrier frequency and the output of your oscillator. As the oscillator frequency is brought closer to the carrier frequency, the pitch of the audio becomes lower. The oscillator frequency is then nearly equal to the carrier frequency.

To set the oscillator to the receiver intermediate frequency, (usually about 455 kHz) connect the 250 pf and 18 pf capacitors into the circuit as shown by the dotted lines in Fig. 16 and tune the oscillator until you hear a squeal in the receiver. This should occur at a dial setting of about 50. Try other stations. They all have the same i-f, therefore they should all have interference.

Disconnect the oscillator circuits from the low voltage power supply whenever they are not being used to minimize undesirable interference.

Will Power and Won't Power

People point out a successful man and say he has a lot of will power. It's true that will power is a necessary requisite of success. But seldom mentioned and just as important is "won't power" – the power to say "No" at the proper time.

"Won't power" alone does not guarantee success in any venture, but when used at the right time, is as important as will power.

When you are tempted to neglect your studies, use *won't* power. If you have not already done so, lay out a schedule for regular study every week and use *will* power to stick to it.

That combination of "I will" and "I won't" can lift you to heights even beyond your fondest dreams today.

John F. Thompson

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ACHIEVEMENT THROUGH ELECTRONICS

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TRAINING KIT MANUAL

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PRACTICAL DEMONSTRATIONS OF RADIO-TV FUNDAMENTALS

INSTRUCTIONS FOR PERFORMING
EXPERIMENTS 61 THROUGH 70

7TT

In this kit you build this complete five-transistor, line-operated AM radio receiver and conduct experiments on it.

Index of Sections

NATIONAL RADIO INSTITUTE, WASHINGTON, D.C. 20016

CEC1M1275 1975 EDITION Litho in U.S.A.

INSTRUCTIONS FOR PERFORMING RADIO-TV EXPERIMENTS 61 THROUGH 70

This transistor radio kit is designed to give you practical experience working with transistor circuits. You are already familiar with the principles of operation of a radio receiver. In previous kits you have worked with typical circuits found in receivers. From your transistor experiments you know how transistor stages operate. In this kit you perform experiments on every stage of an all-transistor radio receiver.

You may or may not have already performed the 7YY experiments on the NRI ac-dc five-tube radio receiver. If you have experimented with the tube receiver, you are familiar with many troubleshooting techniques that are common to both tube and transistor receivers. That experience will help you with your transistor radio troubleshooting. For example, a block diagram of an AM receiver will apply to either type; the same signals are present in the various sections of either type of receiver.

However, from the standpoint of practical servicing, the receiver types are quite different. Big differences are found in the voltage level of signals in various sections of the receiver. The impedance levels tend to be very low in transistor circuits compared to similar points in tube circuits. Many test procedures that work on tube receivers are useless on transistor sets.

On the other hand, if you have not experimented with the tube set, it will not cause difficulties. This transistor radio set of experiments is complete in itself, just as the tube experiments are complete. After you complete these experiments on the transistor receiver, you may want to obtain the 7YY Kit on the tube receiver. Both kits give you practical experience in troubleshooting radio receivers. The 7YY Kit helps you learn to service tube receivers and the 7TT Kit pertains to transistor receivers.

Before you perform the experiments in this kit, you assemble the receiver. The set goes together quickly because most of the parts are mounted on a printed circuit board. Since this may be your first experience with printed circuit boards, you are given instructions pertaining to soldering, replacing components, and repairing printed circuit boards.

Even if you have worked with printed circuit equipment, you can learn from these instructions. We have included some extra printed circuit wiring on the board especially for these instructions. Since this part of the board is not used for the radio, you don't have to worry about damaging the foil. You experiment with this wiring before any parts are mounted on the board.

You complete the receiver and test it before you run the experiments. In some experiments, you remove and replace components from the circuit board. This duplicates parts replacement, which is often performed when repairing receivers. In one of your final experiments, you practice alignment procedures and finally peak up your receiver for best operation. After completing the experiments you install the receiver in its cabinet. You then have an attractive table model receiver for your own use.

CONTENTS OF THIS KIT

In this kit you receive all the parts necessary for building your complete transistor radio. Additional parts are supplied for experiments. Some of the parts for the experiments are parts that are left over from previous kits.

IMPORTANT: The oscillator and i-f transformers supplied in this kit have been preset. Do not move the adjustments on these transformers until you are told to do so. The use of preset transformers assures that your receiver alignment will be accurate enough to receive some stations when you complete construction. After you have the set in operation, you will be instructed how to improve the alignment.

The parts for building the radio are illustrated in Fig. 1 and listed below the photograph. The parts used in the experiments are listed separately. The list indicates those parts left over from previous experiments that will be used again here.

Check the parts you receive against the Parts List to be sure you have all of them. If any part in the kit is obviously defective or has been damaged in shipment, return it to NRI immediately, as directed on the packing slip included in this kit.

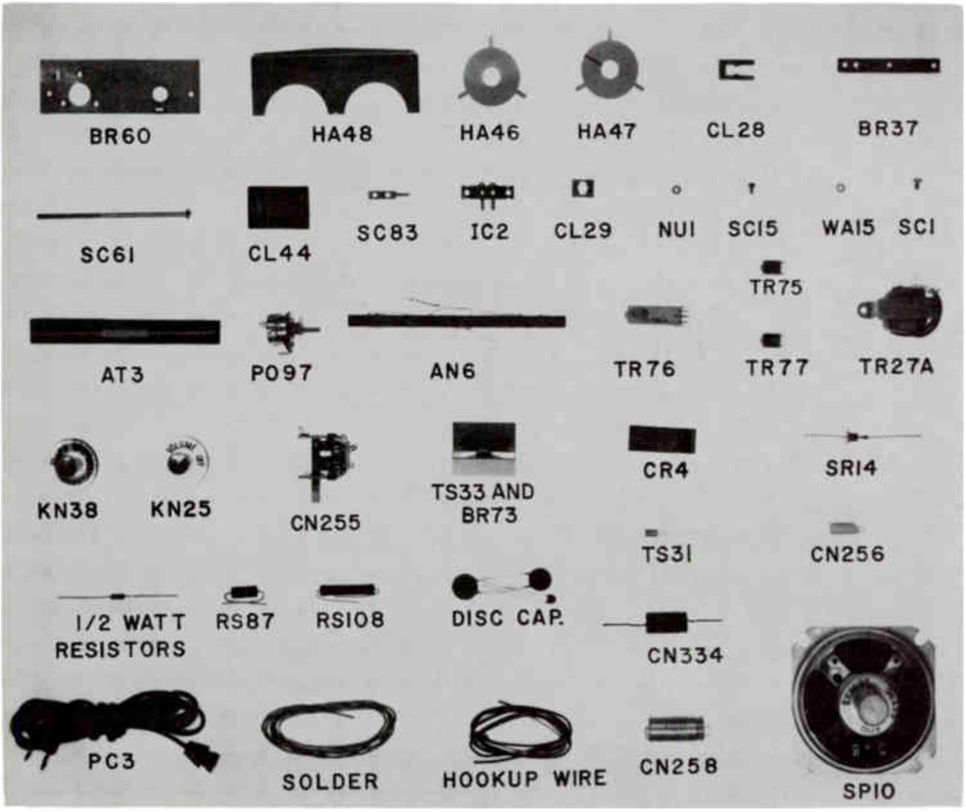


Fig. 1. Parts used to construct Kit 7TT.

Quan.	Part No.	Schematic Symbol	Description	Price Each
1	AN6	L_1	Loopstick antenna	.78
1	AT3		Alignment tool	.32
2	BR37		Chassis support brackets	.16
1	BR60		Volume control bracket	.16
1	BR73		Heat sink	.40
*1	CB15		Radio cabinet	3.15
1	CL28		Power cord clamp	.15
4	CL29		Speaker mounting clips	.02
2	CL44		3/8″ cable clamps	.05
1	CR4	D_1	Detector diode	.35
1	EC21		Etched circuit board	4.72
1	HA46		Plain round dial plate	.20
1	HA47		Round dial plate w/red line	.35
1	HA48		Gray edge molding	.40
1	HA16		10′ length solder	.20
1	IC2		Interlock	.25

*not shown

Quan.	Part No.	Schematic Symbol	Description	Price Each
1	KN25		Volume control knob	.38
1	KN38		Tuning knob	.38
12	NU1		6-32 hex nuts	12/.15
*1	PA17		Front panel	1.50
1	PC3		Interlock power cord	.46
1	PO97	P_1	2.5K-ohm volume control pot w/switch and control nut	.76
9	SC1		1/4" X 6-32 screws	12/.15
2	SC13		3/8" X 6-32 screws	12/.15
8	SC15		No. 6 X 1/4" self-tapping screws	12/.15
2	SC61		4-1/4" X 8-32 screws	.12
2	SC83		1" X 6-32 spade bolts	.06
1	SP10		4" .05 oz. magnet speaker	1.59
1	SR14	D_2	Rectifier diode	.64
1	TR27A	T_4	Audio output transformer	1.00
1	TR75	T_1	Oscillator transformer	.31
1	TR76	T_2	Input i-f transformer	1.31
1	TR77	T_3	Output i-f transformer	.40
4	TS31	Q_1, Q_2, Q_3, Q_4	EN1132 transistors	.46
1	TS33	Q_5	High voltage NPN power transistor	1.90
2	WA5		No. 8 flat metal washers	12/.15
15	WA15		No. 6 split ring lockwashers	12/.15
1	WR257		7" red hookup wire	**
1	WR258		7" white hookup wire	**
1	WR259		48" black hookup wire	**
CAPACITORS				
1	CN180	C_{14}	6.8 pf disc	.15
1	CN229	C_6	220 pf disc	.15
1	CN34	C_7	.001 mfd disc	.15
1	CN245	C_9	.005 mfd, Z5F disc	.15
2	CN86	C_{20}, C_{24}	.01 mfd, 1kV disc	.15
1	CN142	C_{15}	.02 mfd, 500V disc	.15
6	CN204	C_5, C_{10}, C_{12} C_{13}, C_{17}, C_{21}	.05 mfd, +80 −20 100V, Z5U disc	.36
1	CN104	C_8	.1 mfd, 50V disc	.34
*1	CN257	C_{18}	100 mfd, 10V elect.	.40
1	CN258	C_{23}	100 mfd, 150V elect.	1.05
1	CN334	C_{22}	220 mfd, 35V elect.	.45
3	CN256	C_{11}, C_{16}, C_{19}	10 mfd, 10V elect.	.40
1	CN255	C_1, C_2, C_3, C_4	2-gang tuning	1.13
RESISTORS				
1	RE26	R_7	100-ohm	.15
1	RE143	R_{16}	180-ohm	.15

*not shown

**additional wire available in 12′ lengths (only) each color.25

Quan.	Part No.	Schematic Symbol	Description	Price Each
1	RE113	R_{17}	270-ohm	.15
1	RE114	R_{14}	560-ohm	.15
1	RE56	R_{10}	680-ohm	.15
1	RE59	R_3	820-ohm	.15
1	RE30	R_8	1k-ohm	.15
1	RE112	R_{15}	1.5k-ohm	.15
1	RE58	R_4	2.2k-ohm	.15
1	RE29	R_{13}	4.7k-ohm	.15
2	RE50	R_1, R_{19}	6.8k-ohm	.15
1	RE31	R_{18}	10k-ohm	.15
1	RE32	R_{11}	18k-ohm	.15
2	RE33	R_2, R_{12}	22k-ohm	.15
1	RE52	R_9	82k-ohm	.15
1	RE61	R_6	270k-ohm	.15
1	RE38	R_5	470k-ohm	.15
1	RS87	R_{20}	10k-ohm, 2 watt	.24
1	RS108	R_{21}	250-ohm, 4 watt	.60

The following parts are used in the experiments:

Quan.	Part No.	Description	Price Each
*1	BA1	1.5V D-cell battery	.16
*1	PO7	1k-ohm potentiometer	.61
CAPACITORS			
1	CN114	27 pf disc	.15
1	CN131	2200 pf	.15
1	CN34	.001 mfd disc	.15
1	CN35	.005 mfd disc	.15
1	CN86	.01 mfd, 1kV disc	.15
1	CN9	.27 mfd, 400V tubular	.25
RESISTORS			
1	RE27	220-ohm	.15
1	RE28	470-ohm	.15
1	RE56	680-ohm	.15
3	RE30	1k-ohm	.15
1	RE111	1.2k-ohm	.15
1	RE58	2.2k-ohm	.15
1	RE50	6.8k-ohm	.15
1	RE31	10k-ohm	.15
1	RE33	22k-ohm	.15

*left over from previous kits

LEARNING TO WORK ON CIRCUIT BOARDS

Etched circuit boards are widely used in all types of electronic equipment. The circuit board, EC21, supplied with this kit is typical of those used in radio and TV receivers. Examine the circuit board carefully. The board is made of a phenolic insulating material with a pattern of copper foil bonded onto one side. The terms "etched circuit" or "printed circuit" board come from the manufacturing process. The stock board consists of the phenolic material with a thin sheet of copper foil bonded to one side.

The circuit pattern is transferred to the foil by a photographic process or a silk-screen process similar to that used in the printing industry. The board is then placed in a chemical bath that etches away the copper foil in those places not covered by the circuit pattern. The board is cleaned. Then the writing and symbols are screened on to the "phenolic" or "component" side of the board. The component leads are soldered to the circuit wiring on the "foil" or "circuit" side of the board.

Certain precautions must be followed when working on circuit boards to prevent damage. The phenolic material is somewhat brittle. It can break easily if it is dropped or if too much pressure is applied to it. An assembled board with heavy components on it is subject to cracking.

Rough handling will sometimes produce a board crack that breaks one or more of the foil circuit paths. These cracks often produce intermittent defects and may be difficult to locate. In cases where you cannot see the crack, it is sometimes easiest to simply flow molten solder along the circuit path where a crack is suspected. The solder will bridge the break and repair the circuit.

On some finished circuit boards, the entire foil surface is covered with solder. The solder is put on as part of the board assembly operation. The component leads are inserted through the holes in the board, the foil side of the board is dipped into a container of molten solder. Solder adheres to all exposed foil and solders all the component leads in place at one time.

Excessive heat can weaken the bond between the foil and the phenolic; heat and pressure will cause the foil to peel off the phenolic. Once the foil breaks clear of the phenolic, it is quite fragile and will break off easily. A 35-watt soldering iron is adequate for assembling or repairing the circuit board. If you use a higher wattage iron, you must not hold it against the foil for too long a time. Excessive heat can also char the phenolic material and produce leakage paths between different circuits on the board.

The foil associated with holes Q, R, S, and T on your circuit board is not part of the radio circuit. This foil is for you to practice on. You can apply enough heat to damage the foil. In steps that follow we even show you the wrong way to solder the circuit board. In this way you will get a feel for how much heat it is safe to apply when constructing or repairing etched circuits.

Practice Wiring to Circuit Board. You will need your hand tools, etched circuit board EC21, and two 1k-ohm resistors (brown-black-red) that are among the parts furnished for experiments.

Bend the leads 90° on each end of a 1k-ohm resistor. Insert the leads through holes Q and S from the phenolic side of the board. Push the resistor firmly onto the board. Spread the leads slightly so the resistor stays in place when you turn the

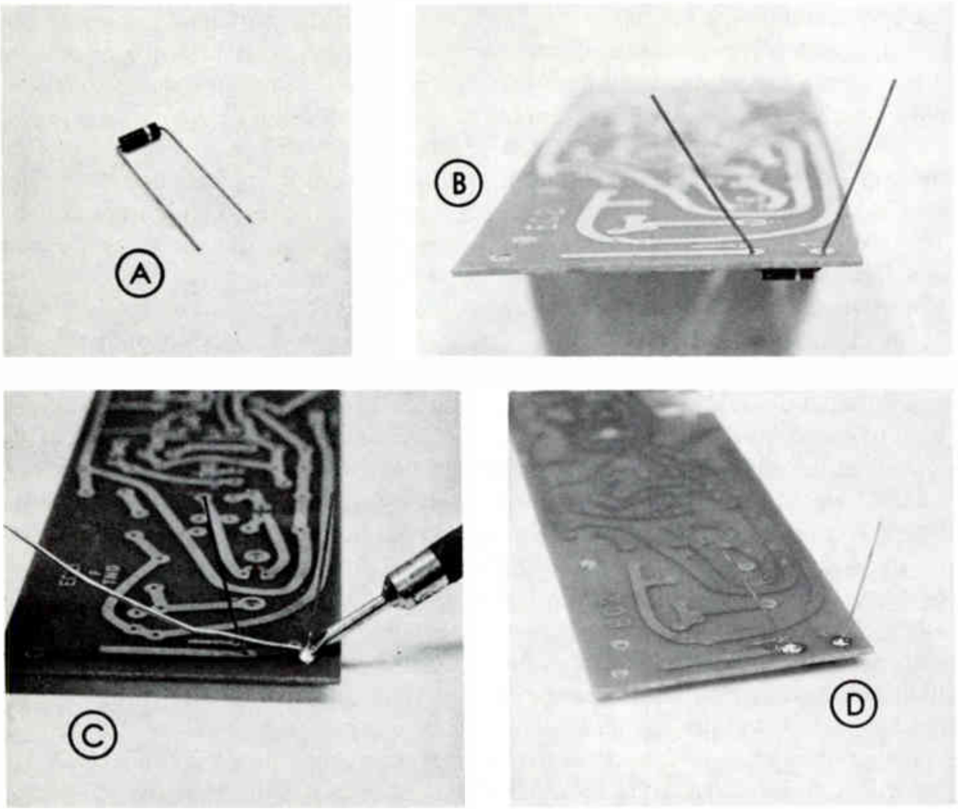


Fig. 2. (A) Bend the resistor leads 90° before inserting into mounting holes of circuit board; (B) bend leads slightly to hold resistor in place during soldering; (C) hold the soldering iron tip in contact with both foil and lead while solder is being applied; (D) use just enough solder to fill in the joint between foil and lead.

board over. Fig. 2A and Fig. 2B show how to install the resistor.

Next hold the hot soldering iron in contact with both the foil and the lead, as shown in Fig. 2C. Touch the solder to the junction of the iron tip and the circuit. Watch the solder spread over the foil and the lead, making sure that it adheres to both of them. Limit the amount of solder that you apply to the junction. Use just enough to produce smooth rounded fillets between the lead and the foil, as shown in Fig. 2D.

Excess solder can be removed by heating the joint and holding the board in a position that lets the solder run down onto the iron tip. Too much solder or too little heat produces round globs of solder that do not "wet" down into the junction. Too little solder leaves the junction weak or fails to fill in all around the lead. Too much heat causes the junction to smoke and the area to change color. When the solder hardens, clip off the lead that extends beyond the soldered connection.

When troubleshooting on a circuit board, it is sometimes desirable to disconnect one end of a component from the circuit. This can be done if you work carefully. Try it on the resistor you just installed at holes Q and S. Simply heat the connection on the foil side at hole Q. Use a scratch awl or thin-bladed screwdriver to pry the resistor away from the phenolic side of the board while you hold the iron tip against the connection. Lift the end of the resistor at hole Q high enough to remove the lead from the hole. The resistor is now positioned so that you can take resistance measurements or other tests for which the resistor must be isolated from the circuit.

Clean the solder out of the hole before you attempt to reconnect the resistor lead to the circuit. A round toothpick makes an excellent tool to clean the solder from the hole. Simply heat the solder, force the end of the toothpick into the hole from the foil side of the board, and remove the soldering iron. The solder will cool and will leave a hole when you remove the toothpick. In place of the toothpick, you can use a wire paper clip or other wire that solder will not stick to.

If you attempt to reconnect the resistor lead without cleaning the hole, you risk pulling the foil loose from the board. When you force the lead through the hole, the lead tends to catch on the edge of the foil in the hole. Heat and pressure will then cause the foil to separate from the board. The narrow sections of foil like that at hole Q are especially liable to damage. Try reconnecting the lead at hole Q. When you are satisfied with the connection, unsolder and remove the resistor from holes Q and S. If the foil is not damaged, reheat the foil at hole Q. Apply enough heat, and if necessary some pressure, so you see what is required to remove the foil.

Examine the unbonded edge of the foil. Notice that it is quite thin and brittle. From this you can see that once the foil separates from the board, that part of the foil can no longer be counted on to form a reliable portion of the circuit. You have to perform additional repairs to the foil circuit for a reliable repair job.

The foil at hole S may have separated from the board when you removed the resistor. When applying heat to the foil on a circuit board, always consider the area of the foil. Hole S has only a small area of foil so it is easy to overheat it. When the foil is wider or covers a larger area, the heat is conducted away from the point where the soldering iron touches and the foil is less likely to be damaged.

Clean the solder off the leads of the resistor that you removed from holes Q and S. Adjust the lead spacing to fit and install the resistor at holes R and T. Seat the resistor body against the phenolic side of the board and carefully solder the lead connection, using the right amount of heat and solder.

How to Repair Broken Wiring. As mentioned before, etched circuits may develop cracks from rough handling. Or during troubleshooting you may want to isolate a component by cutting the foil on a circuit board. In either case you need to repair the break to put the circuit back in operation. Simulate this condition by cutting the foil that extends from hole R. Use a pocket knife or razor blade to make a narrow cut at right angles to the strip of foil, as shown in Fig. 3A. Only a little pressure is necessary to cut through the foil. You can check with an ohmmeter to be sure that the foil is separated. Next, touch your soldering iron to the foil on one side of the cut. Flow some solder onto the heated foil. Notice that the solder does not readily flow across the cut. A hairline crack can often be exposed by this means. The solder melts right up to the crack, but the crack prevents the heat from conducting to the parts of the foil beyond the break.

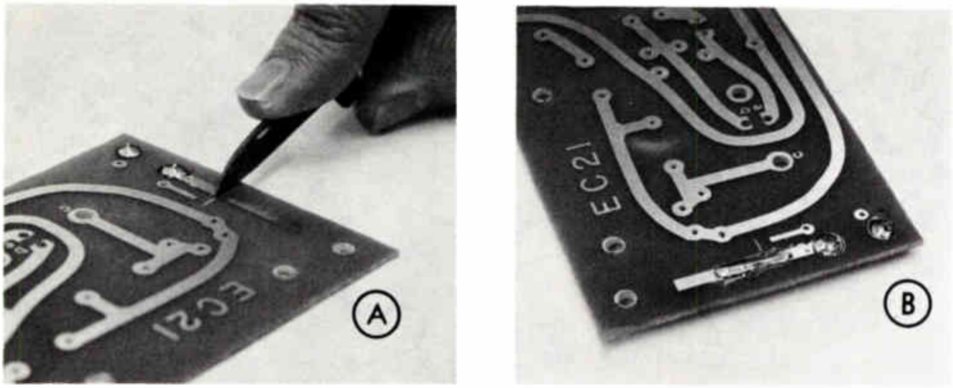


Fig. 3. (A) Cut through the foil to break the etched circuit board wiring, (B) the broken circuit can be bridged by soldering a piece of wire to foil.

Flow some solder onto the foil on the other side of the break and bridge the molten solder across the break. For a narrow break where the phenolic has not been damaged, this repair is adequate. However, if you made a wide cut you may have trouble getting the solder to bridge across it. In that case, reinforce the break with a short piece of bare hookup wire. Simply lay the wire along the foil so it extends across the break and solder it in place, as shown in Fig. 3B. The repair is stronger than the original circuit.

This repair technique can be varied to repair almost any damaged circuit foil. On occasion, you may wish to repair a board where the phenolic is cracked or where a piece has actually broken off the board. A stronger repair can be made by drilling a small hole on each side of the break. Use bare hookup wire to join the two sections together. Then solder the wire to the foil while holding the pieces of the board together in place.

How to Replace Components from the Top of the Circuit Board. The circuit board for your 7TT receiver is not very crowded with components. The parts have been spread out, so it is easy to assemble and perform experiments on the board. This will not always be true for sets that you may have occasion to repair. In some radios and on many TV receivers, the parts are densely packed on the circuit board. In other cases it is difficult to remove the board or reach the foil side of the board. Replacing a component from the top of the board may save you hours of work. You can practice this type of repair by replacing the resistor that you have installed at holes R and T of your circuit board.

Fig. 4 shows the steps involved in replacing a resistor from the top of the board. Use your diagonal pliers to crush the body of the resistor, as shown in Fig. 4A. Use your longnose pliers to straighten the short resistor leads that extend above the board, as shown in Fig. 4B. Next, bend the leads of the replacement resistor to attach them to the short leads extending through the board holes. The 1k-ohm replacement resistor may or may not be placed against the circuit board, depending upon how much room you have to work in. Twist the wires about half a turn so that connections are mechanically secure, as shown in Fig. 4C. Now solder

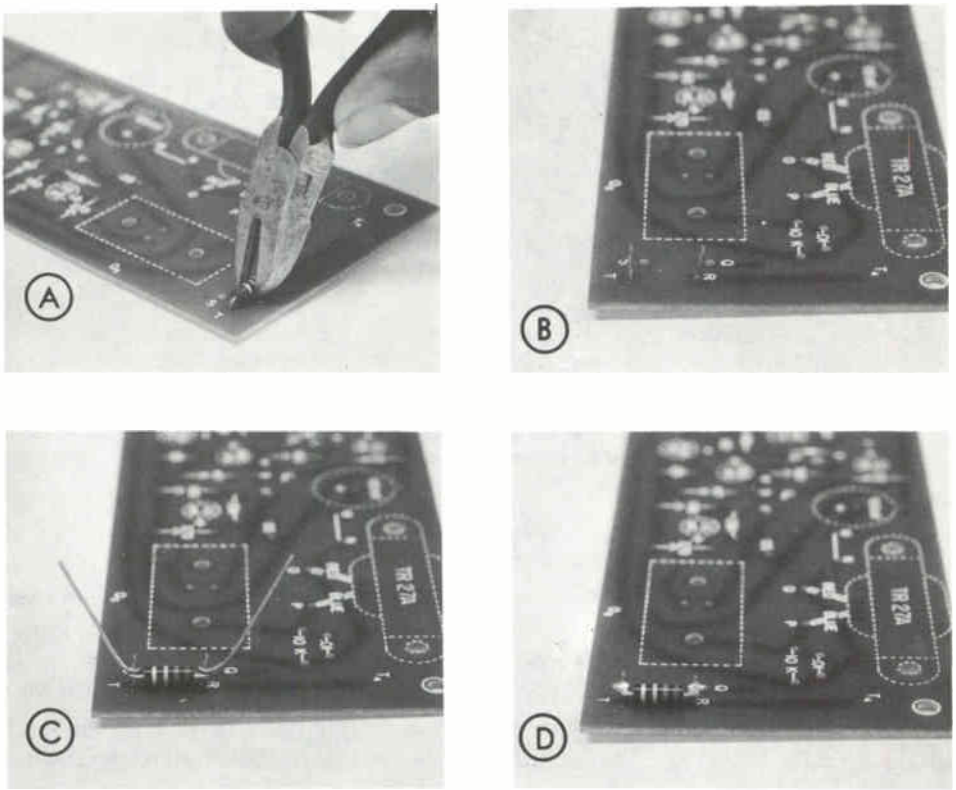


Fig. 4. Steps in replacing a resistor from the component side of the board. Crush the resistor with pliers as shown at (A); straighten the remaining leads as shown at (B). Connect the new resistor leads to the existing leads as shown at (C); solder the connections and clip off the excess lead length as shown at (D).

both joints. Make the solder connections quickly so you do not melt the solder that connects the original resistor leads to the foil on the board. Use your diagonal pliers to trim off the excess wire for a neat connection, as shown in Fig. 4D.

The techniques you practice here can be adapted to almost any repair problem that you will encounter when working on circuit boards.

Unsolder and remove the resistor that you connected at holes R and T.

Assembling Your Experimental Receiver

Your assembly work on your receiver is divided into three sections. First you assemble the etched circuit board. Then you assemble the parts that attach to the front panel. Finally you attach the assembled circuit board to the front panel and perform the interconnecting wiring.

When you perform the assembly work on this kit, remember that you are manufacturing a complete receiver. This is quite different from assembling an experimental kit where you expect to tear down the assembly after you complete the experiments. In this kit you are expected to make permanent wiring connections and be careful with parts placements and lead dress. Take the necessary time and effort to do a professional job. You will be repaid in pride of workmanship, and you will have the satisfaction of the set working the first time you turn it on.

Read and understand the entire sentence or paragraph of each step before you perform the work. Position each part and lead according to the description and illustrations. After you have completed each step, place a check mark in the space provided. This will ensure that you complete the steps in the correct sequence and do not omit any.

ASSEMBLING THE CIRCUIT BOARD

In this section you mount and solder the parts that attach to the circuit board. The instructions for mounting the parts are contained in Figs. 5, 6, 7, and 8. (Figs. 6, 7, and 8 are in the center of this book.) Fig. 5 is a detailed drawing. Fig. 6 shows the steps for mounting the resistors; Fig. 7 shows the steps for mounting the capacitors; Fig. 8 gives the steps for mounting the transformers, transistors, and diodes. Be sure to read all the instructions for work that you must perform before you carry out steps shown in the figures.

Mounting the Resistors. You will need your hand tools and soldering iron at your work surface. Gather the following parts:

1	Etched circuit board (EC21)
1	AC interlock (IC2)
2	1/4" X 6-32 screws
2	No. 6 lockwashers
2	6-32 hex nuts
1	82k-ohm resistor
1	470k-ohm resistor
1	270k-ohm resistor
2	22k-ohm resistors
1	18k-ohm resistor
1	10k-ohm, 2W resistor
1	10k-ohm, 1/2W resistor
2	6.8k-ohm resistors
1	4.7k-ohm resistor
1	2.2k-ohm resistor
1	1.5k-ohm resistor
1	1k-ohm resistor
1	820-ohm resistor
1	680-ohm resistor
1	560-ohm resistor
1	270-ohm resistor
1	250-ohm, 4W resistor
1	180-ohm resistor
1	100-ohm resistor
	Black hookup wire

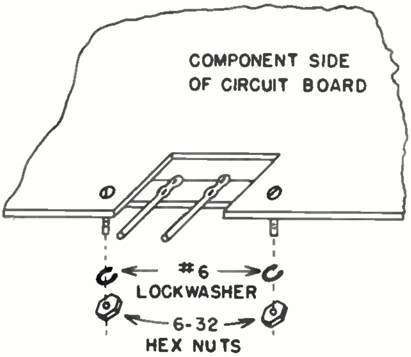


Fig. 5. Details for mounting the ac interlock at the cutout on the board.

Mount the ac interlock in the cutout at the rear edge of the circuit board. Place the interlock on the foil side of the board with the metal pins up toward the phenolic side of the circuit board, as shown in the detailed drawing, Fig. 5. Insert 1/4" X 6-32 screws through the mounting holes from the phenolic side of the board. The screws extend through the mounting holes of the interlock. Attach a No. 6 lockwasher and a 6-32 hex nut to each screw. Tighten the screws . . . . (✓)

Next, perform the steps for mounting the resistors and jumpers as outlined in Fig. 6. When you install a resistor, measure the part against the two mounting holes that the leads are to go in. Then bend the leads so they are at right angles to the body of the resistor, and so that the leads fit into the mounting holes. Put the leads through the holes from the phenolic side of the board. Bend the leads slightly on the foil side of the board so that the part will not fall out before it is soldered in place.

After you have mounted a few parts, stop and solder the leads to the copper on the foil side of the board, and then clip off the excess lead lengths.

NOTE: Use only RADIO ROSIN-CORE SOLDER. This is the type we supply with this kit. Do not use acid-core solder or paste flux. Either will ruin a circuit board so that it cannot be repaired. We cannot repair any kit on which acid-core solder has been used.

INSTALLING THE RESISTORS

In steps 5, 11, and 21 of Fig. 6, form each jumper from a piece of bare wire. Resistor lead scraps will do nicely. Install the jumpers from the component side of the board.

In step 20 of Fig. 6, the 250-ohm, 4-watt resistor connects between one mounting hole and one terminal of the ac interlock. Since this resistor gets warm in operation, mount it so the body of the resistor is from about 1/8" to about 1/4" above the board. The 2-watt resistor used in step 18 should be mounted about 1/8" above the board. All other resistors are mounted tight against the board.

In step 21 of Fig. 6, connect the jumper from hole G of the circuit board to the adjacent terminal of the ac interlock.

When you have completed the steps outlined in Fig. 6, place a check mark here . . . . (✓)

INSTALLING THE CAPACITORS

You will need the following parts:

1 220 pf disc capacitor
1 6.8 pf disc capacitor
1 220 mfd at 35 VDC electrolytic capacitor
1 100 mfd at 150 VDC electrolytic capacitor
1 100 mfd at 10 VDC electrolytic capacitor

3 10 mfd at 10 VDC electrolytic capacitors
1 .1 mfd disc capacitor
6 .05 mfd disc capacitors
1 .02 mfd disc capacitor
2 .01 mfd disc capacitors
1 .005 mfd disc capacitor
1 .001 mfd disc capacitor

The instruction steps for mounting the capacitors are contained in Fig. 7. When you mount the electrolytic capacitors, be sure to observe the polarity markings. A plus mark is screened on the circuit board near the hole for the positive lead of the capacitor. The 100 mfd capacitor installed in Step 8 may not have the positive lead identified. It is the lead in the center of the capacitor body, while the negative lead is bent down along the outside of the body. In Step 14, bend the positive lead down along the body of the capacitor before you install it. The circuit board may be screened "200 mf" at this location.

When you have completed all the steps outlined in Fig. 7, place a check mark here ....(✓)

INSTALLING THE TRANSFORMERS, TRANSISTORS, AND DIODES

You will need the following parts:

1 Oscillator transformer (TR75)
1 Input i-f transformer (TR76)
1 Output i-f transformer (TR77)
1 Audio output transformer (TR27A)
4 EN1132 transistors
1 Power transistor
1 Heat sink (BR73)
1 Detector diode
1 Power rectifier diode
4 3/8" X 6-32 screws
6 No. 6 lockwashers
4 6-32 hex nuts
2 No. 8 flat metal washers

The instruction steps for mounting the listed parts are contained in Fig. 8. Be sure to identify these parts carefully when installing them. It is very difficult to unsolder and remove the 5 or 6 terminals if you happen to mount a transformer in the wrong place.

In step 4 of Fig. 8, a green dot on the base of the transformer is used to identify terminal 1 of the transformer. Position the transformer so the dot on the transformer matches the dot indication on the screening of the circuit board.

In step 9 of Fig. 8, position the audio output transformer on the phenolic side of the board so the bare wires extend toward the edge of the board. Insert 3/8" X 6-32 screws through the mounting feet of the transformer and place a No. 8 flat washer over each screw. Pass the screws through the mounting holes in the circuit board so the two washers are between the mounting feet and the board.

Attach a No. 6 lockwasher and a 6-32 hex nut to each screw. Tighten the screws. Shorten the red and blue transformer wires to a length of about 2". Strip off about 1/4" of insulation from the end of each lead. Solder the red lead of the transformer into hole O and the blue lead into hole P, as shown in Fig. 8.

Consult the detailed drawing, Fig. 9, for identification of the transistor leads for steps 2, 3, 5, and 8. Mount these transistors about 1/4" above the board so the leads are not pulled tight against the mounting holes. You can use an alligator

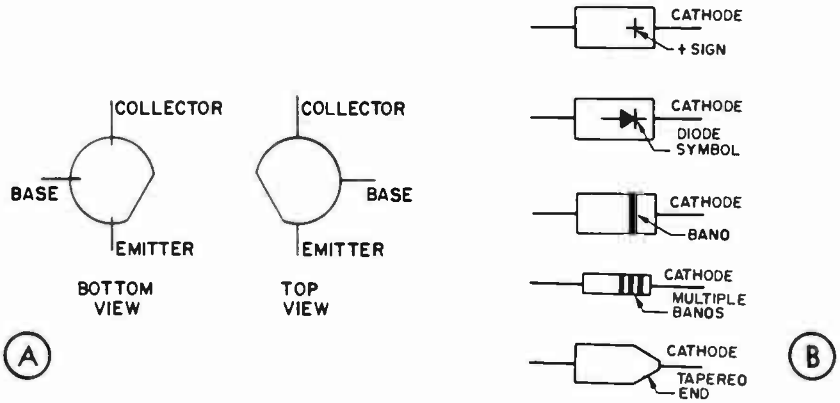


Fig. 9. How to identify transistor leads (A) and diode polarity (B).

clip as a heat sink while soldering the leads of the transistors. Simply attach the alligator clip to the lead on the component side of the board. Turn the board over and solder the connection.

In step 10 of Fig. 8, mount the power transistor (TS33) and its heat sink (BR73) with two 3/8" X 6-32 screws, four No. 6 lockwashers, and two 6-32 nuts (see detail A). First place the transistor inside the heat sink so that its pins pass through the small holes in the center of the heat sink, and so that the transistor mounting holes line up with the large holes at the ends of the heat sink. Pass a 3/8" X 6-32 screw through the transistor and heat sink holes at each end. Then put a No. 6 lockwasher on each screw. Now attach the assembly to the circuit board with two more No. 6 lockwashers and two 6-32 nuts. Be sure to position the transistor so that its pins plug easily into the circuit board. Finally, tighten the mounting hardware and solder the two transistor pins to the circuit board foil. Observe the polarity of the diodes for steps 7 and 11 of Fig. 8.

When you have completed the steps outlined in Fig. 8, place a check mark here .... ( )

This completes the assembly of your circuit board. Examine your work carefully. Look for poor solder connections where you used too little heat or too much solder. If necessary, reheat the connection and remove excess solder. Make sure you have not bridged solder from one part of the foil to the foil in another circuit. When you are satisfied with your work, set the board to one side while you assemble the other parts of the receiver.

ASSEMBLING THE FRONT PANEL

In this section you fasten parts to the front panel. Some hardware and parts are put together as an assembly before you attach the assembly to the panel. Treat the panel with care, because rough handling can mar the plastic finish or even crack the mounting posts.

You will need your hand tools and the following parts:

1 Front panel
1 Dial plate with red line
1 Plain dial plate
1 Gray edge mounting
2 Circuit board support brackets
2 Spade bolts

- 1 Tuning capacitor
- 1 Volume control bracket
- 1 Volume control with switch
- 1 Loopstick antenna
- 1 Speaker
- 2 3/8" cable clamps
- 8 1/4" No. 6 self-tapping screws
- 4 Speaker mounting clips
- 3 1/4" X 6-32 screws
- 4 6-32 hex nuts
- 5 No. 6 lockwashers

Attach Trim to the Front Panel. Refer to Fig. 10A and Fig. 10B as you mount the decorative trim on the front panel.

Position the dial plate with the red line so that the red line is pointing straight up. Put the dial plate in the upper recess of the panel after bending the three tabs so they pass through slots 1, 2, and 3 of the panel as shown in Fig. 10A. The red line should be between slots 1 and 2 . . . . (✓)

Put the plain round dial plate in the lower recess after bending the three tabs so they pass through slots 4, 5, and 6. (✓)

Mount the gray edge molding so the four mounting tabs pass through slots 7, 8, 9, and 10. Slot 9 is on the rear edge of the panel . . . . (✓)

With the three trim pieces pressed firmly against the front panel, bend the 10 mounting tabs as shown in Fig. 10B (✓)

Circuit Board Support Brackets. The next step will be to prepare the support brackets and fasten them to the front panel (as shown in Fig. 11 and Fig. 12).

Attach a 6-32 hex nut to each of the two spade bolts. Tighten the nuts against the "spade" part of the bolt . . . . ( )

Fasten one of the 6-32 spade bolts in hole B of one of the support brackets as shown in Fig. 11. Position the "spade" part parallel to the short dimension of the bracket and secure with a No. 6 lockwasher and a 6-32 hex nut . . . . ( )

In a similar manner, fasten the other

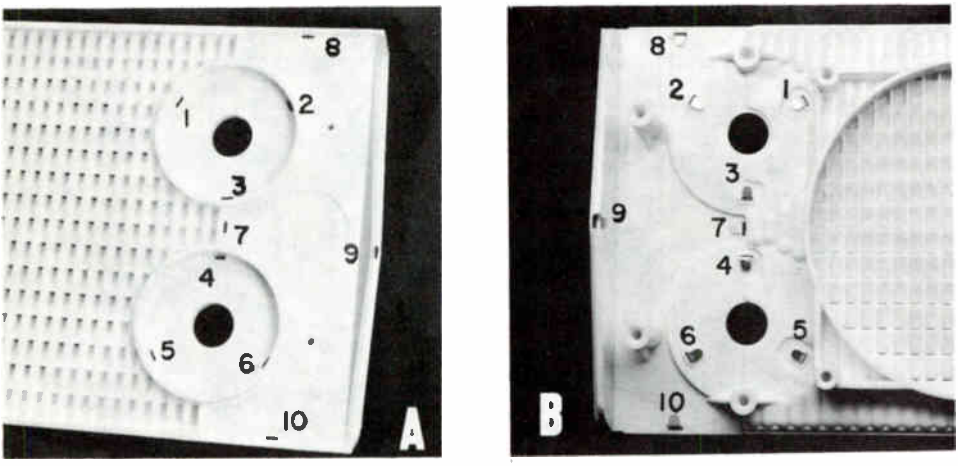


Fig. 10. Mounting the slots for panel trim (A); bending mounting tabs of panel trim (B).

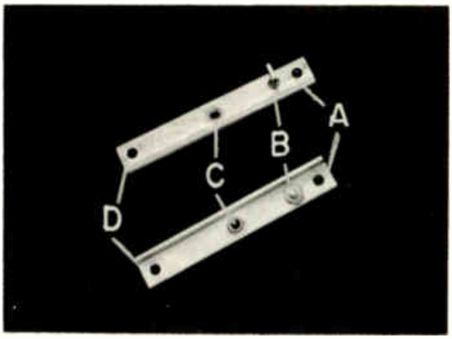


Fig. 11. Circuit board mounting brackets.

6-32 spade bolt in hole B of the other support bracket . . . . ( )

Place the front panel face down on a cloth in front of you. Position the two large holes in the panel to your left, as shown in Fig. 12.

Place one of the support brackets over the two posts on the left of the panel. Position the bracket so that holes A and D are over the holes in the ends of the posts. The "spade" part of the spade lug should be nearest you and pointing straight up. Fasten the bracket to the front panel with two 1/4" No. 6 self-tapping screws. It is important that you tighten these screws very slowly and that you do not overtighten them. As you turn the screw, it cuts threads in the plastic. If the screw starts to turn hard, back off about a quarter turn and again tighten the screw. This will tend to clear the threads and enable you to get the screw all the way in without cracking the plastic. The plastic posts, although strong, may crack if too much force is used in tightening these screws . . . . ( )

In a similar manner, fasten the other support bracket to the two posts on the right end of the front panel. Fig. 12 shows the support brackets mounted in place . . . . ( )

Mount the Speaker. Position the loudspeaker on the front panel with speaker lugs S1 and S2 to your right, as shown in Fig. 12 . . . . ( )

Push a loudspeaker mounting clip over each of the four loudspeaker mounting posts on the front panel. Make sure that the speaker presses evenly at all points against the front panel . . . . ( )

Mount Parts on the Volume Control Bracket. Set the front panel out of your

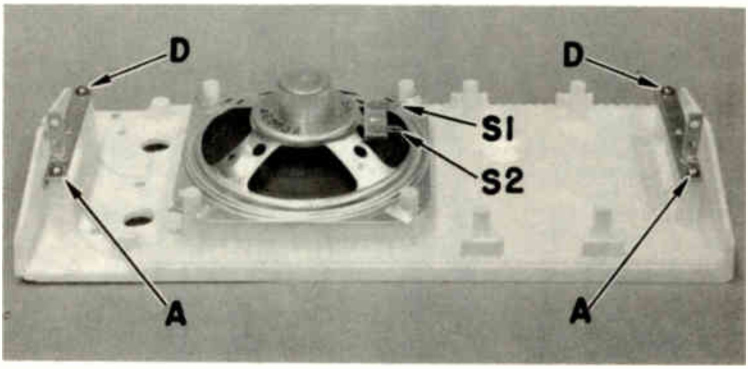


Fig. 12. Rear view of front panel with support brackets and speaker mounted.

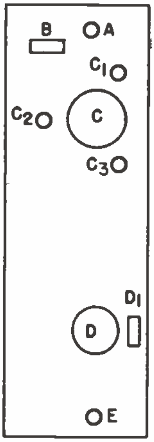


Fig. 13. Rear view of volume control bracket with holes identified.

way temporarily while you assemble the parts on the volume control bracket. Fig. 13 shows a rear view of the bracket with the holes identified. Fig. 14 shows the bracket with the parts mounted.

Slip the shaft of the volume control potentiometer through hole D from the rear of the bracket. Position the control so the locating lug extends through hole D_1. Attach a control nut and tighten it firmly . . . . ( )

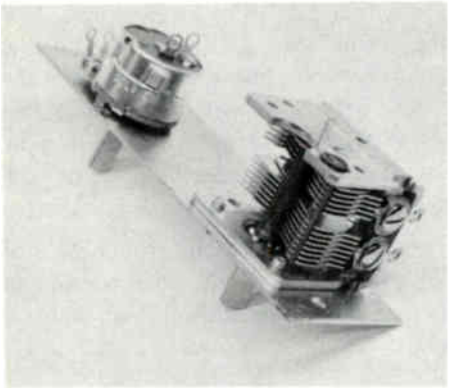


Fig. 14. Volume control bracket with parts mounted.

Slip the shaft of the tuning capacitor through hole C from the rear of the bracket. Position the capacitor so holes C_1, C_2, and C_3 line up with the three threaded holes in the tuning capacitor frame. Slip a No. 6 lockwasher over each of three 1/4" X 6-32 screws. Insert a 1/4" X 6-32 screw with lockwasher attached into holes C_1, C_2, and C_3 from the front of the bracket. Tighten the screws into the threaded holes in the frame of the capacitor . . . . ( )

Attach Volume Control Bracket, Antenna. Fig. 15 shows the front panel with all parts, except the circuit board, mounted in place. Position the volume control bracket, with parts attached, to the rear of the front panel so the shafts extend through the control shaft holes. In this position, holes A and E in the volume control bracket line up with mounting posts on the front panel.

Insert 1/4" No. 6 self-tapping screws through holes A and E and into the mounting post holes. Carefully tighten the screws into the plastic. Do not over-tighten . . . . ( )

Examine your loopstick antenna. The black ferrite core is quite brittle and will break rather easily if it is dropped. Also be careful not to apply any flexing pressure to the rod. The rod is partially covered with two wire windings. The long winding forms the coil for the rf tank circuit. The short winding is the secondary winding that carries the received signal to the input circuitry of the receiver. As shown in Fig. 15, the short winding end of the loopstick goes toward the tuning capacitor.

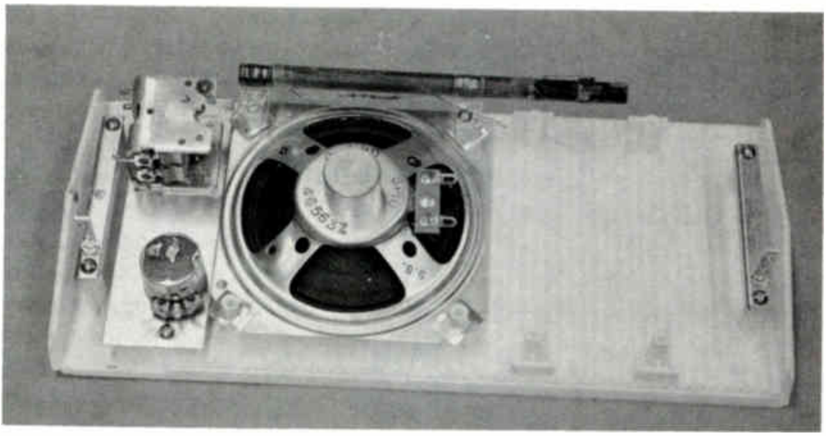


Fig. 15. Rear view of front panel with all parts, except the circuit board, mounted in place.

Slip a 3/8" plastic cable clamp over the long winding section of the loopstick. Slip another 3/8" plastic cable clamp over the bare end of the ferrite core at the short winding end. Hold the antenna next to the two top speaker mounting posts and slide the cable clamps to fit the posts. Insert 1/4" No. 6 self-tapping screws through the cable clamp mounting holes and into the holes of the speaker mounting posts. Tighten the screws carefully. Do not overtighten . . . . (✓)

FINAL ASSEMBLY AND WIRING

In this section you attach the assembled circuit board to the assembled front panel and complete the final wiring of the receiver. Fig. 16 shows a top view of the completed wiring. Fig. 17 shows a bottom view of the completed wiring.

You will need the assembled front panel, the preassembled circuit board, and:

1	Tuning knob
1	Volume control knob
2	1/4" X 6-32 screws
2	No. 6 lockwashers
2	6-32 hex nuts
	Assorted hookup wire

Position the circuit board to the rear of the panel so the board rests on the spade portion of the spade lugs. Position the board so the two board mounting holes line up with the holes in the spade lugs. Use the holes farthest from the panel so the board clears the switch terminals and speaker. Insert a 1/4" X 6-32 screw from the top of the board into each mounting hole. Attach a No. 6 lockwasher and 6-32 hex nut to each screw. Tighten the nuts firmly . . . . (✓)

Connect a 1-1/4" wire from hole A of the circuit board to one terminal of the on-off switch. Insert the wire into the hole from the top of the board. Route the wire over the edge of the board to the switch terminal. Solder both of the connections . . . . ( )

Connect a 1-1/4" wire from hole B of the circuit board to the other terminal of the on-off switch. Solder both connections . . . . ( )

Connect a 2-3/4" wire from hole C of the circuit board to the solder lug on the frame of the tuning capacitor. Solder hole C of the circuit board . . . . ( )

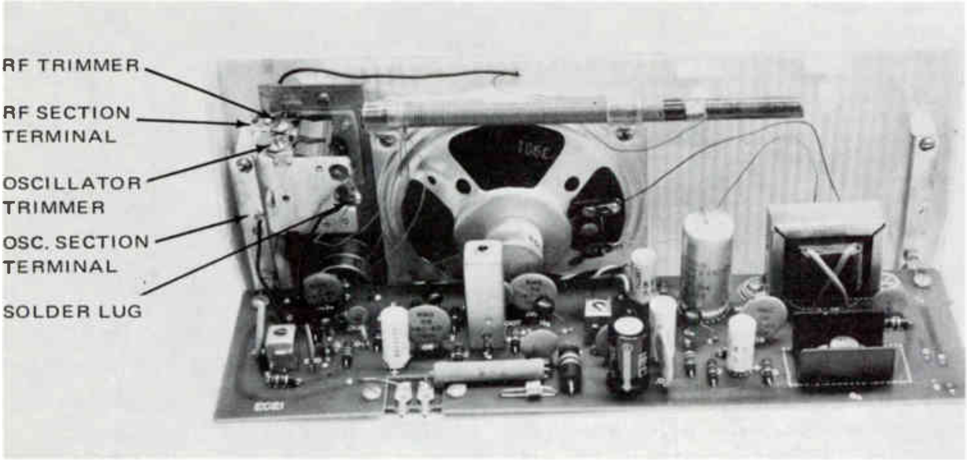


Fig. 16. Top view of receiver with wiring completed.

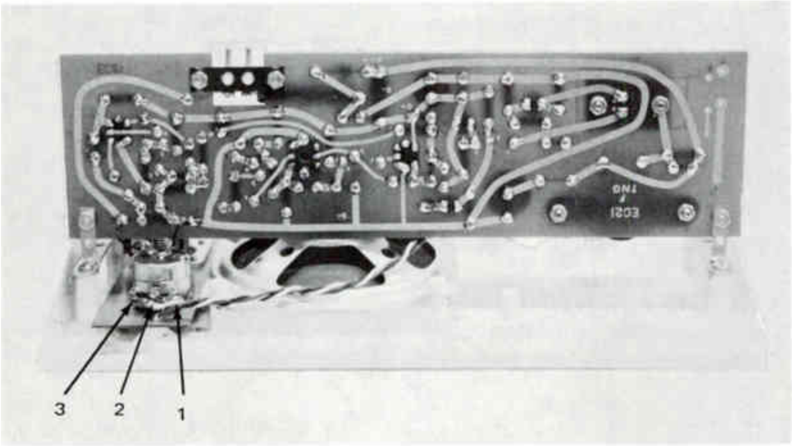


Fig. 17. Bottom view of receiver with wiring completed.

Connect a 2-1/4" wire from hole D of the circuit board to the terminal on the oscillator section of the tuning capacitor. Solder both connections . . . . ( )

Locate the two varnished wires from the secondary of the audio output transformer. Connect a transformer wire to each speaker terminal. Solder both terminals . . . . ( )

Prepare a 7" cable from three pieces of hookup wire. Cut a 7" piece each of red, white, and black hookup wire. Twist the three wires together so that they form a loose cable. Strip 1/4" of insulation off of the end of each piece of wire in the cable . . . .( )

Refer to Fig. 18 when you perform the following steps.

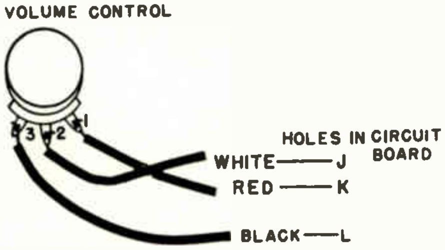


Fig. 18. Details for wiring the volume control to the circuit board.

Connect the wires at one end of the 7" cable to holes J, K, and L from the top of the circuit board. The white wire goes into hole J, the red wire into hole K and the black wire into hole L. Solder all three wires to the foil on the circuit board .... ( )

Route the end of the cable over the front edge of the circuit board and over to the volume control potentiometer terminals .... ( )

Connect the red wire of the cable to terminal 1 of the volume control potentiometer. Solder the connection .... ( )

Connect the white wire of the cable to terminal 2 of the volume control potentiometer. Solder the connection .... ( )

Connect the black wire of the cable to terminal 3 of the volume control potentiometer. Solder the connection .... ( )

Identify the wires from the coils of the loopstick antenna. Two wires come from the short secondary coil and two wires come from the long rf coil. These wires are rather fragile and can be broken by rough handling. If you break a wire, or if a wire is too short to reach the indicated terminal, splice on a piece of hookup wire to reach the terminals.

Connect one wire from the short secondary coil of the loopstick antenna to hole E of the circuit board. Solder the wire to the foil .... ( )

Connect the other wire from the short secondary coil of the loopstick to hole F of the circuit board. Solder the wire to the foil .... ( )

Connect one wire from the long rf coil of the loopstick to the solder lug on the frame of the tuning capacitor. Solder the connection .... ( )

Connect the other wire from the long rf coil of the loopstick antenna to the terminal on the rf section of the tuning capacitor. The rf section contains the largest number of plates and is the section nearest the front panel. Route the wire close to the front panel. Solder the connection .... ( )

Push the tuning knob onto the shaft of the tuning capacitor .... ( )

Push the volume control knob onto the shaft of the volume control potentiometer .... ( )

This completes the assembly and wiring of your receiver. You will not install the receiver in the cabinet until after you perform the experiments. Examine your work carefully. Look for bits of wire that may have fallen on top of the circuit board. Look for unsoldered connections, poorly soldered connections, or globs of solder that could cause short circuits. When you are satisfied with your work, proceed to the next section where you are given instructions for testing the receiver.

Testing and Analyzing the Receiver

In this section, you become familiar with your receiver circuitry in preparation for performing the experiments. You record a set of voltage and resistance measurements on your receiver. This assures you that your receiver is wired correctly. Also, you use the recorded voltage measurements as a reference when you are performing the experiments.

As you know, the voltage measurements will vary from set to set. These variations are caused by normal parts tolerances. When you record a set of readings using your own meter on your own receiver, you have a valid set of readings that you can refer to. This is important for analyzing results of experiments. The accurate readings are also helpful in case you have to troubleshoot your receiver.

For this section you will use two important illustrations that are located in the center of the book. Fig. 19 is the schematic diagram of the receiver. You will want to keep this diagram handy to follow circuit discussions. Fig. 20 is a "see-through" diagram of the circuit board. This diagram shows the circuit board as it appears from the foil side of the board. The components are shown in schematic form as they would appear if you could see through the circuit board. Use this drawing to locate test points in the circuit and parts on the circuit board.

CAUTION

Dangerous voltages are present in your receiver. As you know, any ac-operated device carries sufficient voltage to kill you. Even if you use an isolation transformer, the lethal voltages are present within the receiver circuitry. The isolation transformer only protects you from a difference in potential between the receiver and an external earth ground.

Since you have not installed the set in the cabinet, you have in effect defeated the purpose of the ac interlock. Observe all safety precautions. If you are not using an isolation transformer, be sure you are standing on an insulated surface. A damp concrete surface is especially dangerous. Do not work close to an earth ground such as a water pipe.

Unplug the line cord when you make changes in the circuitry. It is almost as easy to unplug the cord from the interlock as it is to turn off the switch. Unplugging the cord gives you complete protection to work on the circuitry. If you work on the energized receiver, steady the set by holding on to the plastic front. Use only one hand to touch live points in the circuit.

Remember that dangerous voltages are present at some points on the component side of the board. For example, the body and vaned heat sink of transistor Q_5 is at the B++ potential of approximately 120 volts dc.

PRELIMINARY TESTS

Before you plug your receiver into the ac power line, you should perform one simple ohmmeter test. Connect the ground clip of your meter to the foil marked B– on the circuit board. Touch the probe to the foil marked B++. You should measure about 4k-ohms of resistance. If you read 0 ohms or a sizable amount less than 4k-ohms, look for a short circuit on the circuit board. Look for solder that is bridged between the B++ and the B– foil on the board. Look for pieces of bare wire that may be shorting between component leads on the component side of the circuit board. If you energize the receiver before clearing the short, you will probably damage components in the power supply circuit.

When you are satisfied that the B++ line is not shorted, energize the receiver. Connect the power line cord to the ac interlock of the receiver. Plug the other end of the cord into a 115-volt ac outlet or into the outlet of an isolation transformer.

Turn the receiver on by rotating the volume control clockwise to actuate the on-off switch. Advance the volume control about halfway. Rotate the tuning knob to tune in a station. Adjust the volume control for normal listening level.

Determine what AM radio stations are available in your area and the transmission frequency of these stations. Your local newspaper probably lists all the local stations, their call letters, and their frequencies.

Tune your receiver across the band and determine if you can receive all available stations. Note the position of the tuning dial for each station to see if your dial indicates the frequencies of the received stations.

The transformers in your receiver are preset so the receiver should be fairly well aligned, but you can improve the alignment. Locate the plastic alignment tool, AT3, that is furnished with the receiver. You will need this tool and a small screwdriver.

Tune the receiver to a weak station. Make sure you are tuned exactly on the station, which is the tuning point where the signal comes in loudest. Using the "see-through" diagram in Fig. 20, locate the input i-f transformer, T_2, on the circuit board. Use your alignment tool to adjust the slugs in the transformer. The hexagon-shaped part of the tool at one end fits the hexagon hole in the transformer slug.

Rotate the top slug either clockwise or counterclockwise, as necessary, to increase the volume of the received station. A fraction of a turn should be all that is necessary to peak the signal. Reach the alignment tool through the hole in the circuit board to adjust the bottom slug in transformer T_2.

Locate the i-f output transformer, T_3. Use a screwdriver to fit the slot in the core at the top of the transformer. Adjust the core as necessary to again peak the received signal. The i-f amplifier is now properly adjusted.

Tune your receiver to the lowest frequency station that you can receive in your area. See if the tuning dial indicates the correct frequency. If not, set the dial to the correct frequency for the station and use a screwdriver to rotate the slug in transformer T_1 in either direction, as necessary, to receive the station.

Next, tune to the highest frequency station that you can receive. Identify the frequency of the station. Observe the position of the tuning dial to see if it indicates the frequency of the received station. If it does not, set the tuning dial to the frequency of the received station and adjust the oscillator trimmer capacitor to receive the station. The oscillator trimmer capacitor is attached to the oscillator section of the tuning capacitor. The oscillator section of the tuning capacitor is the section farthest from the front panel and having the fewest plates. Use a screwdriver to adjust the screw in the trimmer capacitor.

If you moved the core of T_1 very far or adjusted the oscillator trimmer very far, repeat these two adjustments until you get no further improvement.

Finally, adjust the trimmer capacitor on the rf section of the tuning capacitor. This is the trimmer closest to the front panel. Tune the receiver to a weak station near the high end of the broadcast band. Adjust the rf trimmer for maximum received signal.

The touch-up alignment adjustments that you just performed should be adequate for now. In your last experiment, you will perform alignment experiments and finally perform a complete alignment procedure on your receiver.

CIRCUIT DESCRIPTION

The line-operated, superheterodyne AM broadcast-band radio receiver shown in schematic form in Fig. 19 uses five transistors and two diodes. Diode D_2 rectifies the 115-volt ac from the power line. The 250-ohm, 4-watt resistor, R_{21}, is a surge-limiting resistor used to limit the current through the diode. The .01 mfd capacitor, C_{24}, protects the diode from line transients. The output of the half-wave rectifier is filtered by C_{23} and supplies about 120 volts dc B++ to the power output stage, Q_5. The B++ voltage is dropped by the 10k-ohm resistor, R_{20}, to about 19 volts B+ to supply all other stages of the receiver. The B+ line is filtered by the 200 mfd capacitor, C_{22}. Capacitor C_{21} is a ceramic disc capacitor used to provide an rf bypass on the B+ line.

The rf signals from broadcast-band radio stations are picked up by the loopstick antenna, L_1. The rf section of the tuning capacitor, C_1, and the trimmer capacitor, C_2, form the capacitor portion of the tuned rf tank circuit of the antenna. The received rf signals are transformer-coupled to the low-impedance secondary winding of the loopstick antenna, L_1.

The rf signal from the secondary is coupled through R_7 to the base of the mixer stage, Q_2. A local oscillator signal is coupled through C_7, developed across R_6 and C_9, and applied through the secondary of L_1 and through R_7 to the base of Q_2.

The local oscillator signal is generated by the transistor Hartley oscillator stage, Q_1. A positive supply voltage is applied through the voltage-dropping resistor, R_{19}, and through the 3-5 winding of the primary of T_1 to the emitter of the PNP transistor, Q_1. The entire primary winding of T_1 forms the inductive portion of the oscillator tank circuit. The oscillator section of the tuning capacitor, C_3, provides the capacitive portion of the oscillator tank circuit. Capacitor C_4 is the oscillator trimmer capacitor in parallel with C_3. The .05 mfd capacitor, C_5, completes the signal path circuit of the tank.

The secondary winding of T_1 provides a feedback path for the oscillator circuit and provides the oscillator output signal that is coupled through C_7 to the mixer stage. The phase of the signal at terminal 4 of the secondary of T_1 is of the correct polarity to sustain oscillation. The signal is coupled through C_6 to the base of Q_1. Transistor Q_1 is biased to its operating point by the potential at the junction of R_2 and R_1.

The 470k-ohm resistor, R_5, and the .1 mfd capacitor, C_8, isolate the capacitor frame and the volume control bracket from B−. As you know, B− connects to one side of the ac power line. If B− is connected directly to the capacitor frame and the volume control bracket, a dangerous situation could develop. It would then be possible to touch one side of the ac line by removing a knob and touching the metal shaft of either the tuning capacitor or the volume control. The R-C network, consisting of R_5 and C_8, provides a signal path to the tuning capacitor frame and keeps ac leakage to a safe value.

The PNP mixer stage, Q_2, is supplied a positive voltage from the B+ line through the 820-ohm dropping resistor, R_3, to the emitter. The collector circuit of Q_2 is completed to B− through the 5-3 tap-down section of the primary of T_2. The tapped winding on the primary of T_2 provides a low impedance match for the collector of Q_2, and the full primary winding and the capacitor across the winding form a high Q tank circuit tuned to the 455 kHz intermediate frequency of the receiver.

The fixed bias network for Q_2 is combined with the avc circuit. The voltage at the junction of R_6 and R_8 is applied through the secondary winding of L_1, and through R_7 to the base of Q_2. B+ voltage is supplied through the detector circuit (and through volume control P_1), through the 18k-ohm resistor, R_{11}, through R_8 and R_6 and returned to B−.

The detected audio signal at the output of the second detector, D_1, is a positive voltage that adds to the positive fixed bias. The larger the signal at the second detector, the larger the positive voltage that is added to the fixed bias. Since a positive voltage on the base of Q_2 acts as reverse bias, a larger detector signal reduces the gain of the mixer stage, Q_2. In this way, avc is applied to the mixer stage. The avc voltage is filtered by the 10 mfd filter capacitor, C_{11}.

An avc voltage is also applied to the i-f amplifier stage, Q_3. To see how this is done, examine the base circuit of Q_3 and the emitter circuit of Q_2. A static or fixed bias is applied to the base of Q_3 by the action of the voltage divider network consisting of R_3, R_4, and R_9. The dc potential at the emitter of Q_2 follows the dc potential at the base of Q_2.

Therefore, when an avc voltage raises the potential at the base of Q_2, the transistor conducts less and the emitter voltage also increases. The voltage at the emitter of Q_2 is filtered by C_{10}. The dc voltage at the emitter of Q_2 is supplied through R_4 and through the 2-6 winding of T_2 to the base of Q_3. In this way, avc voltage changes are applied to the base of Q_3 and affect the gain of the stage.

Since a positive avc voltage is applied to both Q_2 and Q_3, the avc voltage is reverse-acting. That is, a strong signal produces a positive avc voltage that reduces the conduction of Q_2 and Q_3, and reduces the gain of both stages.

The selected rf station signal and the local oscillator signal are heterodyned in the base-emitter junction of transistor Q_2. Amplified sum and difference signals, plus the two original signals, appear in the collector circuit of Q_2. The tuned i-f amplifier transformer, T_2, selects only the difference, 455 kHz, and rejects all other frequencies. The 455 kHz i-f signal is transformer-coupled to the secondary of T_2 and applied to the base of Q_3.

Transistor stage Q_3 is a transformer-coupled, neutralized, i-f amplifier. The amplified i-f signal is developed in the primary winding of the tuned i-f transformer, T_3, and coupled to the low impedance, untuned secondary winding of T_3. A sizable interelement capacitance exists between the base and collector of the transistor. The interelement capacitance can cause degeneration and loss of gain. Or when the collector load is inductive, it is possible for the capacitance to cause oscillation. To prevent this capacitance from causing degeneration, the capacitance is neutralized by the neutralizing capacitor, C_{14}. The signal at terminal 4 of T_3 is of the correct polarity to neutralize the effect of interelement capacitance in the transistor when the i-f is tuned to 455 kHz.

Now the signal from the secondary of transformer T_3 is applied to the second detector circuit. Diode D_1 rectifies the i-f signal and capacitor C_{15} filters the rectified signal. The detected audio signal is developed across the volume control potentiometer, P_1.

The desired amount of audio signal is picked off by the slider of P_1 and coupled through the 10 mfd electrolytic coupling capacitor, C_{16}, to the base of the audio driver stage, Q_4. The operating point for Q_4 is set by the voltage divider network consisting of R_{13} and R_{12}. The PNP transistor, Q_4, is supplied from the B+ line through the 560-ohm bypassed emitter resistor, R_{14}. The collector circuit is completed to B− through resistors R_{15} and R_{16}.

The amplified audio signal at the collector, Q_4, is direct-coupled to the base of Q_5. Since the circuit is direct-coupled, the collector potential for Q_4 is also the base voltage for Q_5. Therefore the operating point for Q_5 is fixed by the average conduction of Q_4.

Transistor Q_5 is an NPN transistor and is supplied from B++ through the primary of the audio output transformer, T_4, to the collector of Q_5. Resistor R_{18} and capacitor C_{20} damp out voltage transients that could exceed the breakdown voltage rating of the transistor. Capacitor C_{17} in the base circuit of Q_5 helps filter signal transients that could develop damaging voltages in the collector circuit of Q_5. The unbypassed emitter resistor, R_{17}, provides negative feedback that reduces distortion originating in the output stage, Q_5.

Capacitor C_{19}, in the emitter-base circuit of Q_5, improves the impedance match and shapes the audio response curve. The audio signal at the emitter of Q_5 is the same phase as the driving signal at the base of Q_5, because the emitter signal follows the base signal. Capacitor C_{19} couples the emitter signal back to the junction of R_{15} and R_{16} in the base circuit of the transistor.

The values of the resistors in the R_{15}-R_{16} network determine the amount of feedback. Since the signals are in phase, the feedback is essentially positive feedback that increases the gain of the stage. Also the positive feedback reduces the driving power required by the signal driving Q_5. This increases the effective input impedance of the Q_5 base circuit, so it more nearly matches the impedance of the collector circuit of Q_4.

The audio response is limited to a band of frequencies from about 100 Hz to about 6000 Hz. Capacitor C_{17} attenuates the high frequencies, including noise. Low frequency roll-off is caused by coupling capacitor C_{16} and by the small inductance of the audio output transformer. The audio section has more than adequate gain for normal strength stations. On strong local stations, the repro-

	VOLTAGE CHART					
	COLLECTOR		BASE		EMITTER	
	TYPICAL READING	YOUR READING	TYPICAL READING	YOUR READING	TYPICAL READING	YOUR READING
LOCAL OSCILLATOR Q1	0 VDC	00V	4.6 VDC	4.2	4.9 VDC	4.4
MIXER Q2	0 VDC	0	18.2 VDC	[illegible]17	18.9 VDC	18.0
I-F AMPLIFIER Q3	0 VDC	0	18.2 VDC	18.0	18.9 VDC	18.5
AUDIO DRIVER Q4	7.2 VDC	7.0	16.2 VDC	16.0	16.9 VDC	16.5
AUDIO OUTPUT Q5	110 VDC	103	7.2 VDC	6.8	6.7 VDC	6.4

	TYPICAL READING	YOUR READING
B++	120 VDC	112
B+	19 VDC	19
AC SUPPLY	117 VAC	114

NOTE: All measurements taken with high-impedance meter. All measurements taken from B– to the indicated test point. Receiver tuned to a point where no station is received.

Fig. 21. Typical voltage readings with spaces for recording your readings.

	RESISTANCE CHART					
	COLLECTOR		BASE		EMITTER	
	TYPICAL READING	YOUR READING	TYPICAL READING	YOUR READING	TYPICAL READING	YOUR READING
LOCAL OSCILLATOR Q1	0-ohm	0	5k-ohm	5K	*900-ohm	6K
MIXER Q2	4-ohm	4	22k-ohm	30K	10k-ohm	10K
I-F AMPLIFIER Q3	2-ohm	2.5	12k-ohm	10K	10k-ohm	10K
AUDIO DRIVER Q4	*900-ohm	600	10k-ohm	10K	10k-ohm	10K
AUDIO OUTPUT Q5	20k-ohm	20K	*900-ohm	600	270-ohm	250

		TYPICAL READING	YOUR READING
B++ LINE		15k-ohm	20K
B+ LINE		10k-ohm	9K
AC SUPPLY	HIGH SIDE	30k-ohm	50K
	LOW SIDE	0-ohm	0

*NOTE: Varies with ohmmeter scale because the reading indicates transistor resistance. Readings taken with ohmmeter section of tvom using the scale that gives the nearest mid-scale reading. Readings taken between B– and the indicated test points. Readings taken with on/off switch in the ON position and the line cord unplugged. Low side of AC supply connects through on/off switch to B–. "Normal-Reverse" switch of tvom to "Normal."

Fig. 22. Typical resistance readings with spaces for recording your readings.

duced sound will distort badly before the volume control is turned wide open. Distortion remains well below 2% for audio output levels below 500 milliwatts. This is more than adequate sound for normal listening levels.

VOLTAGE AND RESISTANCE CHARTS

The voltage chart in Fig. 21 and the resistance chart in Fig. 22 give typical readings obtained on the CONAR Model 7TT receiver. Spaces are provided in the charts to record your own readings on your receiver. Use the schematic diagram of the receiver, Fig. 19, and the "see-through" drawing of the circuit board, Fig. 20, to locate the test points on your receiver. Be sure to observe the notes on the charts that give you the setup conditions for taking the readings. You will find these charts very useful in understanding the effects of defects that you insert in the receiver circuitry when performing experiments.

Performing Experiments 61 Through 70

Your receiver should now be in good operating condition for performing the experiments. In performing these experiments, you often remove parts and make circuit changes. We usually remind you to test the receiver after you complete each change. If you fail to correct a wiring change and go on with the experiment, you can end up with confusing symptoms.

As you complete each experiment, perform the step for answering the statement question. Be sure to read carefully all choices for each statement. In some cases a choice may be partially correct. In other cases you have to choose the most nearly correct of several choices. If you have made careful observations while doing the experiment and the step for the statement, you will have no trouble answering the statement. Take special care to correctly transfer your answers to the Report Statement sheet that you mail in for grading.

EXPERIMENT 61

Purpose: To show that a meter can be used to indicate the presence or absence of signals in certain stages of a transistor radio receiver.

Introductory Discussion: Your meter (vtvm or tvom) can often be used to quickly isolate a defect in a radio receiver. In this experiment you examine the capabilities and limitations of the meter for determining if signals are present in certain stages of the receiver.

It is convenient to be able to test for signals with the meter. When you first open the defective receiver, one of your first tests may be to check for the presence of the required power supply voltage. For this test, you would normally use your meter.

Since you have the meter hooked up to the receiver, it is convenient to use it to test for signals. In most cases, a reading or two with your meter will isolate the trouble to one section of the receiver or even to a particular stage. At least you will be able to eliminate several of the possible causes of the defect. Also, the results of your test will indicate to you what other methods of investigation should be used to locate the defect in the particular receiver you are working on.

In this experiment, you will examine what signals can be observed using only the meter. You may know of better ways to test a particular function of a receiver. For example, a circuit disturbance or signal injection method is probably the quickest and easiest way to test the audio section. But you can also trace the audio signal with your meter.

An experienced serviceman will always have several different methods of testing to choose from. He may use an alternate method of testing to prove a suspected defect, or special conditions may make the preferred test method impractical.

Knowing many test methods improves your understanding of circuit operation. It also reduces the chance of your being stumped by an unusual defect that does not respond to your usual preferred test methods.

Experimental Procedure: To perform the steps of this experiment, you need only your operating receiver and your meter.

Set the receiver on your work surface with the foil side of the printed circuit board facing you. A convenient position is with the chassis resting on its left end. The left edge of the front panel and the left edge of the circuit board support the receiver in a stable, upright position. In this position, the weight of the receiver is not resting on any parts that could otherwise be damaged. Also you can reach both sides of the circuit board. Tack-solder a short piece of hookup wire to the B– foil. This provides a convenient place to clip the common lead of your meter.

Use the schematic diagram of the receiver (Fig. 19) to follow the discussions relating to circuit operation. Use the "see-through" diagram (Fig. 20) of the circuit board to locate test points and components on the circuit board.

Test your receiver operation both before and after each step of an experiment; otherwise, you may introduce another defect before the previous one is corrected. This can cause waste of time, confusing results from an experiment, or damage to some components of your receiver.

Step 1: To show how the meter can be used to localize a defect causing a dead set to one section of the receiver.

The audio detector is the dividing line between the rf section and the af section of a receiver. A test at this point will isolate the defect to either one of these two signal-handling sections of the receiver. This test is a logical first step in isolating the defect in a dead receiver.

Tack-solder a short piece of hookup wire across the voice coil terminals of the speaker. This will simulate a dead receiver and allow you to turn the volume control maximum without the annoyance of the loud audio. Connect the ground clip of your meter to B– on the receiver. Set your meter to measure +dc on the 30-volt range. Touch the meter probe to terminal 3 of the volume control, P_1. You should read 15 volts or more.

From the schematic diagram, notice that the volume control is connected to the B+ line, so you will read approximately B+ anywhere in the detector circuit. Notice also that terminal 3 of P_1 connects to the output of the detector diode. Therefore, the detected audio signal will simply add to the B+ voltage value.

Tune the receiver slowly across the band while observing the meter pointer. The reading increases when you tune to a station, indicating that the detector is rectifying the received signal.

Move the ground clip of your meter to terminal 1 of the volume control, P_1. Turn the Range switch to the 3-volt range. Again touch the probe to terminal 3 of the volume control and tune across the band. With the meter hooked up this way, the meter indicates only the voltage produced by the action of the diode detector. On strong stations, you may get a reading of .5 volt or more. A very weak station may produce a reading of only .1 volt. Between stations, the pointer returns to zero.

This test tells you definitely that the rf section is working, and that the defect lies in the af signal path between the detector and the speaker.

Step 2: To trace a signal through the audio section of the receiver with a meter.

Leave the receiver and test equipment set up as you had it for Step 1. Switch the meter Function switch to ac and again touch the probe to terminal 3 of P_1. On a strong station, you should observe that the meter needle fluctuates a small amount, but does not give a very definite reading. Connect the ground clip of the meter to B– and touch the probe to the base of Q_4. When the volume control is turned fully clockwise, the ac reading will be about the same as that obtained at the output of the detector.

If you are used to working with tube radios, you may find these results unusual. As you know, the transistor is a current-operated device. The output of the detector must work into the relatively low impedance of the base circuit of the driver transistor. Therefore, the volume control potentiometer is 2.5k-ohms instead of about one-half a megohm, as usually found in tube receivers. Also, the coupling capacitor is 10 mfd instead of the .01 to .05 mfd commonly found in tube sets. This circuit is designed to vary the base current of the driver transistor. Therefore, the ac voltage variations are too small to give a usable indication on the meter.

Next, switch the Range switch of your meter to the 12-volt scale and touch the probe to the collector of the driver transistor, Q_4. You should read between 1 and 6 volts, depending on the strength of the station you are tuned to. The meter reading will fluctuate with the contents of the program. Vary the volume control setting, and notice that the amplitude of the reading also varies. Touch the meter probe to the emitter of Q_4. You do not get a reading because the emitter resistor, R_{14}, is well bypassed by the capacitor, C_{18}.

From the schematic diagram, notice that the signal at the collector of Q_4 is also the signal at the base of Q_5 because the transistors are direct-coupled. Next, touch the probe to the emitter of Q_5, and again observe a reading similar to that obtained at the base. This is what you would expect, because the emitter resistor, R_{17}, is not bypassed, and the emitter signal tends to follow the base signal.

Turn the Range switch to the 120-volt position and touch the probe to the collector of Q_5. With the volume control fully clockwise and tuned to a strong station, you should read 50 or 60 volts ac. The reading will fluctuate with changes in the audio signal.

From these tests you can see that the meter is not very good for tracing the audio signals in the circuit immediately following the detector of a transistor receiver. However, you do get a usable indication in the stages after the signal has been amplified. Therefore, the test can isolate the defect to a very small section of circuitry. For example, suppose your test indicates that the detector is working but you do not get a signal at the collector of the driver transistor, Q_4. The suspected circuitry would include the coupling capacitor, C_{16}, the transistor Q_4, and its associated circuitry.

Step 3: To show that the meter can be used to indicate the presence of signals in some stages of the rf section of the receiver.

Unsolder and remove the short piece of hookup wire that you connected across the terminals of the speaker. In this step you can turn the volume down to the desired level and it will not affect the readings in the rf section of the receiver. Tune the receiver to a strong local station. Set the meter to read ac on the lowest range. Connect the ground clip to B- and touch the probe to terminal 4 of T_3, which is the junction of the i-f output transformer and the detector diode.

You should get a readable indication of about .25 to .5 volt if you are tuned to a strong station. Tune across the station, and notice that the reading is greatest when properly tuned, and drops to zero between stations. Also notice that touching the probe to this point in the circuit does not noticeably affect the volume of the recovered sound. The secondary of the i-f output transformer is a low-impedance circuit, so the capacitance of the probe does not detune or load the circuit appreciably.

Next, touch the probe to terminal 2 of T_3, and again read an indication of the presence of the 455 kHz i-f signal. Notice that touching terminal 2 detunes the primary circuit and lowers the volume of the recovered sound. Touch the probe to terminal 6 of T_3, which is also the collector of Q_3, and read an indication of the i-f signal. This point is a lower impedance than terminal 2, so touching it produces little or no detuning. Touch the probe to the base of Q_3 and look for an indication on the meter. The signal is too small to give you a usable indication.

Touch the meter probe to the collector of Q_2 and tune to a strong local station. You should read some small value of ac voltage as an indication of the presence of a signal. The meter gives a fair-sized indication, because four signals are present at this point.

As you know, the collector of the mixer, Q_2, carries the oscillator signal, the incoming rf signal, the sum of these, and their difference, or i-f signal. The combined effect of these four signals is sufficient to produce a reading on the meter. Attempt to measure the signal at the base of Q_2. The local oscillator signal is coupled to the base circuit through C_7 and the rf signal is direct-coupled from the loop antenna. However, these signals are too small at this point to give an indication on your meter.

Next, use your meter to determine if the local oscillator is operating. Touch the probe to terminal 4 of the oscillator transformer and measure a small value of ac voltage. Tune the receiver across the band, and notice that the amplitude varies somewhat at different points. This is normal, since the efficiency of the oscillator varies for different frequencies. The amplitude variations are unimportant as long as the oscillator signal is above the minimum amplitude required to properly operate the mixer stage.

Touch the probe to the base and then the emitter of Q_1. The oscillator signal is too small at these points to produce a usable meter indication. Touch the probe to terminal 2 of T_1 and measure an ac voltage of 2 to 5 volts. Since this measurement is taken across the high-impedance tank circuit, you get a sizable reading. Tune the receiver across the band, and notice the large change in oscillator voltage amplitude at various settings of the tuning capacitor.

The results of this step show that the meter has limited value for tracing signals in the rf section of the receiver. However, the ability to use the meter to determine that the local oscillator is operating is very useful in troubleshooting. Also, being able to determine that an i-f signal is present in the i-f output transformer is useful. For example, suppose you get no indication of an audio signal at the output of the detector. If you then read an i-f signal at the i-f output transformer, you can be pretty sure that the detector diode is open. If the diode is shorted, it will, of course, short the i-f signal to the detector filter circuit and no appreciable signal can be measured on the i-f output transformer.

Instructions for Statement 61: For this statement you will use your meter to determine if the local oscillator is operating, and investigate the effect of meter loading, if any, on the operation of the receiver.

When servicing the receiver, it is convenient to measure the local oscillator signal at the tuning capacitor because this point is easy to locate in the circuit. You know that the local oscillator tunes to a frequency higher than the incoming rf signal. Therefore, the small section (fewer plates) of the tuning capacitor is the variable capacitance for the local oscillator. To take the reading you simply clip the ground lead of the meter to B-, touch the probe to the capacitor terminal, and measure the ac oscillator voltage.

Perform the preceding test on your receiver. Attempt to tune in a station while the probe is in contact with the capacitor terminal. Remove the probe, tune in a station, and again touch the probe to the capacitor terminal. Observe the effect, if any, on the received signal, then answer the statement.

Statement No. 61: When I touched the meter probe to the terminal of the oscillator tuning capacitor to measure the local oscillator voltage,

(1) the meter probe loaded the circuit only slightly and I was able to receive most stations at their usual places on the tuning dial.

(2) the meter probe capacitance changed the frequency of the local oscillator and the few stations I could tune to appeared at the wrong place on the tuning dial.

[✓ *(3)*] *the meter probe loading shunted out the radio station i-f signals, so I was not able to receive any stations.*

EXPERIMENT 62

Purpose: To show how to use a circuit disturbance test to isolate a defective stage.

Introductory Discussion: A circuit disturbance test is the equivalent of a signal-injection test. As you know, signal injection consists of injecting the type of signal normally carried by the circuit to some point in the signal path and determining if the circuit processes the signal. For example, if an audio signal is injected into any point in the audio signal path circuits, the amplified audio signal should be heard from the loudspeaker.

If a modulated i-f signal is injected anywhere in the i-f amplifier circuit signal path, the circuit should amplify the signal, the detector should detect the audio modulation, the audio amplifier should amplify the detected signal, and you should again hear the processed signal from the loudspeaker. Likewise, a modulated rf signal can be applied to the antenna to test the operation of all circuits in the receiver.

In practical servicing, a circuit disturbance test is usually substituted for signal injection because it is quicker and produces satisfactory results. For a circuit disturbance test, you need only change the level of the dc voltages somewhere in the signal path to produce an audible click at the speaker.

In the audio section of the receiver, you can inject a 60 Hertz signal by merely touching your finger to the signal path. Your body picks up enough 60 Hertz signal from the house wiring to provide a usable signal for the high-gain audio amplifier stages. You will then hear a 60 Hertz hum from the speaker.

In a transistor receiver, touching the signal path in the rf or i-f section of the receiver may or may not produce enough disturbance to get a click at the loudspeaker. As you know, the slight change in dc operating voltage levels must shock-excite the tuned circuit in the stage. This will produce a few cycles at the resonant frequency of the tuned circuit. The oscillations quickly die out. The change in amplitude of the rf signal constitutes the modulation, so the detector produces a small signal that is reproduced in the speaker as a click. At some points in a low impedance transistor circuit, touching the low impedance point may not produce enough change to be heard in the speaker.

Experimental Procedure: For this experiment you will need your operating receiver, your meter, your hand tools, and the following part:

1 .27 mfd capacitor

Step 1: To show that a sudden change in current through the output transformer primary will produce a click in the loudspeaker.

Unplug the receiver from the power line. Set the Function switch of your meter to ohms and the Range switch to the lowest range. Clip the meter ground lead to the collector of the output transistor, Q_5. Touch the ohmmeter probe to the B++ line. Observe the schematic to see that with this connection you are placing the ohmmeter across the primary of the audio-output transformer. You should hear a click in the speaker each time you make or break the connections. The battery in your ohmmeter is forcing a small amount of current through the primary of the transformer. The change in current through the primary induces a current in the secondary that drives the voice coil of the speaker to produce the click. Remove the meter ground clip from the collector of the output transistor.

This procedure tests the audio output transformer and the speaker. This is an easy test to make on these parts when testing a dead receiver. If this test does not produce a click, then you would use the ohmmeter to measure continuity through the transformer primary and secondary and through the voice coil of the speaker.

It is necessary to disconnect one wire from the speaker to measure its continuity. Both the secondary of the transformer and the voice coil are in parallel and both have a very low resistance.

Many receivers do not have an audio-output transformer. Instead, the voice coil of the speaker is driven directly from the output transistors. In these receivers it is sometimes necessary to disconnect one lead of the speaker to make a valid resistance check of the speaker voice coil.

Step 2: To show how a circuit disturbance test can be used to prove whether or not the audio section of the receiver is operating.

Connect the receiver to the power line and tune to a point between stations. Turn the volume control fully clockwise. If you are in a noisy location, you will hear a lot of noise from the loudspeaker. To get rid of the noise, tack-solder a short piece of hookup wire from terminal 3 to terminal 4 of the i-f transformer, T_3. This simulates a defect in the i-f section of the receiver.

Touch the blade of a screwdriver to terminal 2 of the volume control (center terminal) and touch your finger to the screwdriver blade. You should hear a 60 Hertz hum from the loudspeaker. Rotate the volume control from maximum to minimum, and notice that the volume drops to zero. From the schematic diagram, you can see that when the volume control is at minimum, terminal 2 is in effect connected to terminal 1, which is also the B+ line. Therefore, the filtering on the B+ line filters the 60 Hz pickup signal from your body and no hum is produced in the speaker.

Touch the screwdriver to the base of Q_4 and again hear the 60 Hertz hum. Notice that varying the volume control still changes the volume. The signal is lost through the large coupling capacitor, C_{16}, to the B+ line when the volume control is turned down. You should still hear a click when you touch the circuit. Next, touch the screwdriver to the base of Q_5, which is also the collector of Q_4. Again you will hear a click, but the 60 Hertz hum is not audible. The single stage does not have enough gain to give a usable indication of the hum signal. The collector of Q_5 is at a high positive voltage of about 110 volts dc. Touch the collector of Q_5 and notice that it does not produce an audible click.

Remove the short circuit that you tack-soldered across terminals 3 and 4 of the i-f output transformer, T_3. Tune to a place on the dial between stations and turn up the volume control. Again perform the circuit disturbance tests in the audio section. Notice that you get a distinct click in the speaker when you touch any point in the audio signal path. Even when you touch B++ or B- you hear a click. This occurs because the disturbance produces an rf signal that is picked up by the antenna. Even though the signal is quite weak, the high gain of the receiver is such that it processes the signal and produces a click in the speaker. From this experiment, you can see why a receiver picks up electrical noise from appliances, machinery, etc.

Step 3: To show how a circuit disturbance test can be used to indicate the operation of an i-f or mixer stage.

Use a clip lead or a short piece of hookup wire to short out the oscillator tank circuit. Connect the short between the capacitor terminal on the oscillator section of the tuning capacitor and the ground lug on the frame of the capacitor. This connection will stop the local oscillator. The signal path through the radio is unaffected, but no stations will be received. Turn the volume control fully clockwise.

Energize the receiver and touch the screwdriver blade to the collector of Q_3. You should get a loud click from the receiver. Touch the base of Q_3, the collector of Q_2, and the base of Q_2. In each case, the circuit disturbance will produce a loud click in the speaker, indicating that the stages are able to pass a signal. Touch the antenna terminal where it connects to the rf section of the tuning capacitor. A disturbance in the rf tank circuit of the antenna induces a signal in the secondary of the loopstick, which in turn acts as a signal to the base of Q_2. Try holding your hand against the wires of the loopstick. You should hear noise and hum from the speaker, depending on the amount of pickup signal available in your area. These tests indicate that the rf and i-f sections of your receiver are capable of amplifying a signal.

Touch your screwdriver blade to the base and then to the emitter of the oscillator transistor, Q_1. Even though the circuit is not oscillating, it amplifies the circuit disturbance and injects a signal to the base circuit of Q_2, producing a click in the speaker.

Disconnect the receiver from the power line and carefully unsolder the collector lead from Q_2. Energize the receiver and again perform the circuit disturbance test in the rf and i-f sections of your receiver. Touching the collector and base of Q_3 produces the usual loud click. Also when you touch terminal 5 of T_2, which is the point where the collector of Q_3 usually is connected, you get a loud click. The circuit disturbance in the primary of T_2 is readily coupled to the secondary to furnish a signal to the base of Q_3.

Touch the base of Q_2 and other points in the signal path ahead of Q_2. You may hear a faint click in the speaker, but not nearly as loud as when Q_2 was operating.

The preceding tests show how you can use the circuit disturbance to isolate the defect to one stage of the receiver.

Step 4: To show limitations of the circuit disturbance tests.

Carefully resolder the connection of the collector of Q_2 to the circuit board. Temporarily disconnect the short on the oscillator section of the tuning capacitor, and test the radio for proper operation. Then disable the oscillator by reconnecting the tuning capacitor short circuit. Next, tack-solder a short piece of hookup wire from terminal 4 of T_2 to B− (the foil at terminal 3 of T_2 is a convenient B− point for the connection). This connection places a short circuit across the primary of the transformer, T_2.

Energize the receiver and perform the circuit disturbance test in the rf and i-f sections of your receiver. When you touch the base and collector of Q_2, you should get an audible click from the speaker. You may note that the sound is not quite as loud as before you shorted the transformer, but the stage is still passing the signal.

Now remove the short from the oscillator section of the tuning capacitor to activate the local oscillator. Attempt to tune in a station. If you have a very strong local station in your area, you will be able to hear it faintly. Unplug the receiver from the power line. Unsolder and remove the short circuit that you had connected from terminal 4 of T_2 to B−. Test the receiver for proper operation.

The results of this step indicate that the circuit disturbance tests have serious limitations. Thus a short in the relatively low-impedance transistor circuit did not prevent the circuit from passing a circuit disturbance signal. In an earlier step, you found that touching the oscillator transistor produced a click even though the oscillator was not oscillating. Therefore, you can see that the circuit disturbance tests give you only rough indications of whether the circuits are working or not. The fact that these tests can be made quickly makes them useful even though they have serious limitations.

Instructions for Statement 62: For this statement you will investigate the effectiveness of stage blocking in the signal path of a transistor receiver. As you know, stage blocking consists of intentionally killing the signal in one stage at a time. This troubleshooting technique is often used for tracking down the point at which noise is getting into the signal path. For example, suppose you block the i-f output stage. If the noise is still present, you know that the noise is getting into the signal path somewhere between the stage and the speaker. On the other hand, if the noise disappears, it must be getting into the signal path in an earlier stage.

For this statement, you will use a .27 mfd capacitor to attenuate the i-f signal in the i-f section of your receiver. Tune your receiver to a local station and adjust the volume for a normal listening level. Next, use a clip to attach one end of your .27 mfd capacitor to B- on the receiver. Then touch the free end of the capacitor to the foil at the collector of Q_2, and note the effect on the received program. Next, touch the free end of the capacitor to the foil at the base of Q_3, and again note the effect on the program. Finally, touch the free end of the capacitor to the foil at the collector of Q_3. Remove the capacitor, test the receiver for proper operation, and answer the statement.

Statement No. 62: When I attempted to kill the i-f signal by shunting a .27 mfd capacitor from the i-f signal path to B-,

(1) the capacitor completely eliminated the signal at each point that I touched.

(2) the capacitor affected the volume only slightly at each point that I touched.

(3) the capacitor killed the signal when I touched the collectors, but I could still hear the program when I touched the base of Q_3 because this is a low-impedance point in the circuit.

EXPERIMENT 63

Purpose: To show how to use the meter to locate a defective transistor.

Introductory Discussion: Your meter can be an effective tool to determine quickly if a transistor is defective. In most cases, you can determine positively whether or not the transistor is defective without removing it from the circuit. You are able to make these tests by knowing what voltage readings are reasonable at each element of the transistor. The voltage readings you take on the transistors should tell you if the transistor is conducting, and if proper voltages are applied to the transistor. From these voltage tests, you should be able to determine if an inoperative stage is the result of a defective transistor or the result of defective circuitry associated with the transistor.

Let's examine each of the few facts that you must remember while you are making voltage tests on the transistor. These facts about transistor voltages apply to any circuit, and do not require you to know the correct voltages for the particular receiver you are working on.

Fig. 63-1 shows a PNP and an NPN transistor symbol, with the polarity of voltages at each element of the transistor. The polarity markings of the collector and emitter are relative to each other. In each case, the base polarity is the same as the collector to provide forward bias for the transistor.

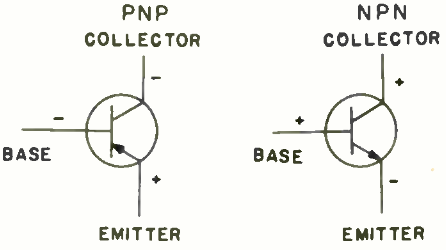


Fig. 63-1. Polarity of the operating voltages at the elements of transistors.

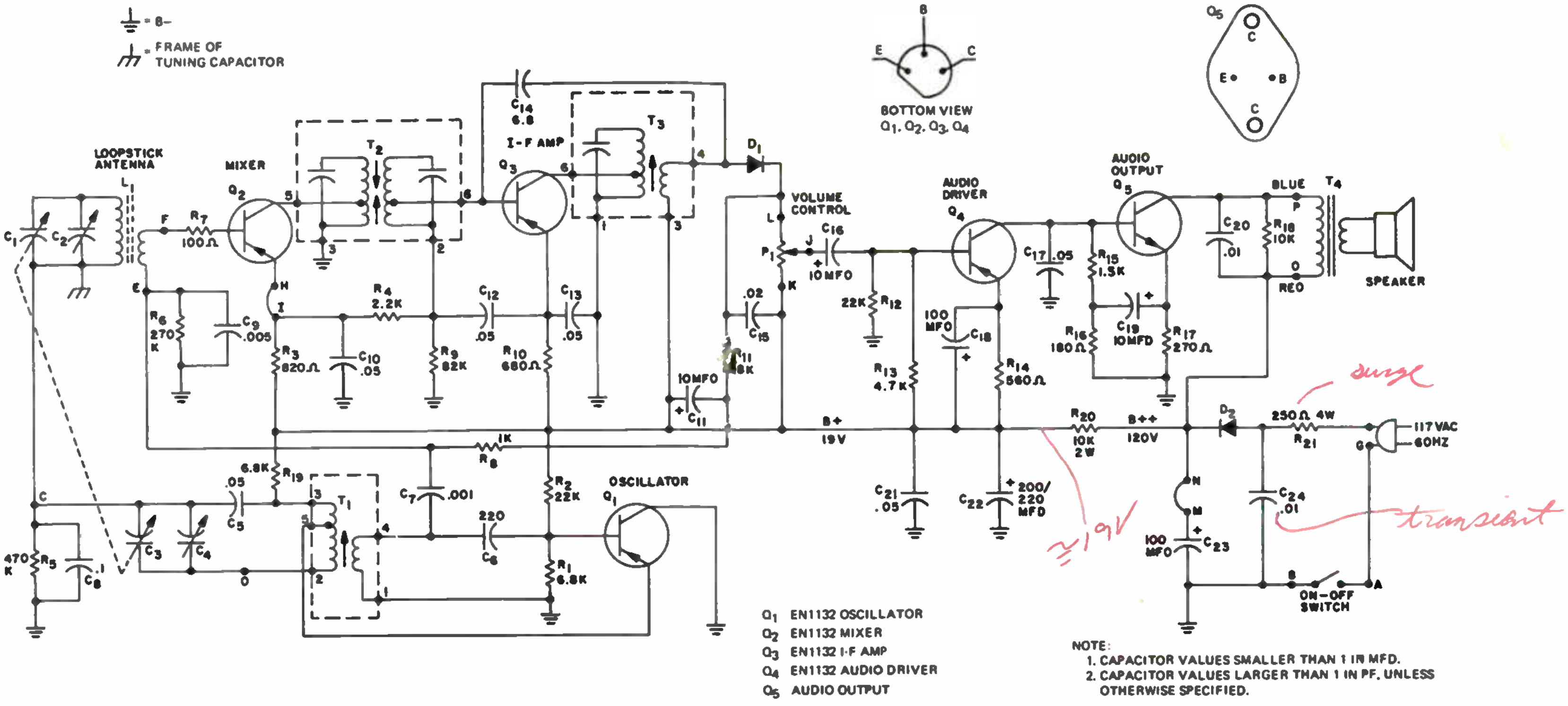


Fig. 19. Complete schematic of 7TT receiver.

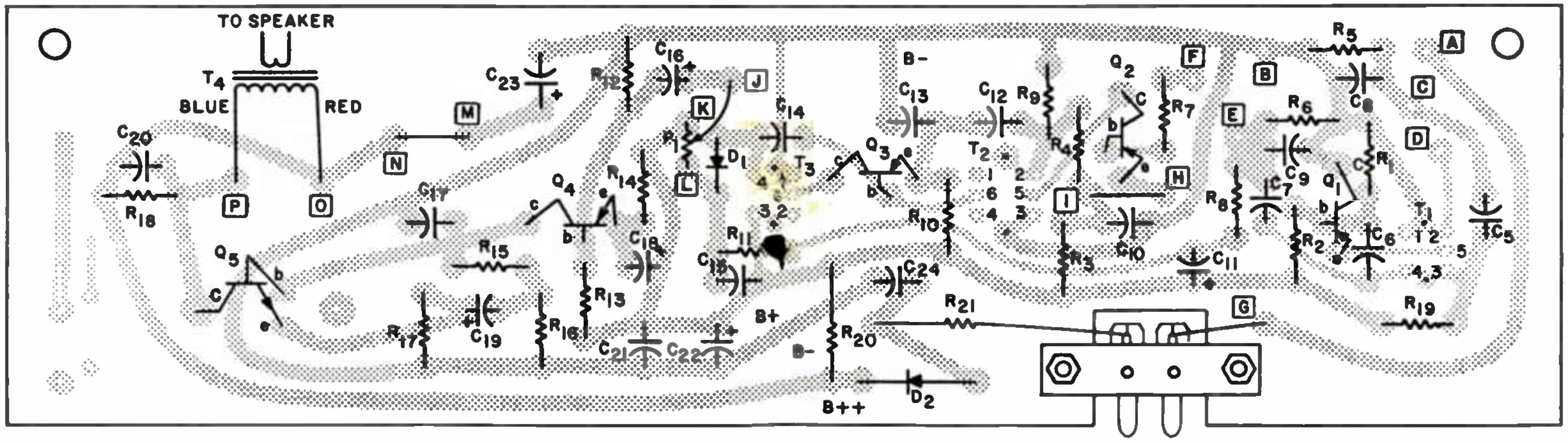


Fig. 20. "See-through" drawing showing location of parts from the foil side of the circuit board.

These diagrams should be removed from the book so you can refer to them quickly and easily. Carefully open the staples, remove the diagrams, and then close the staples again so the book will not fall apart.

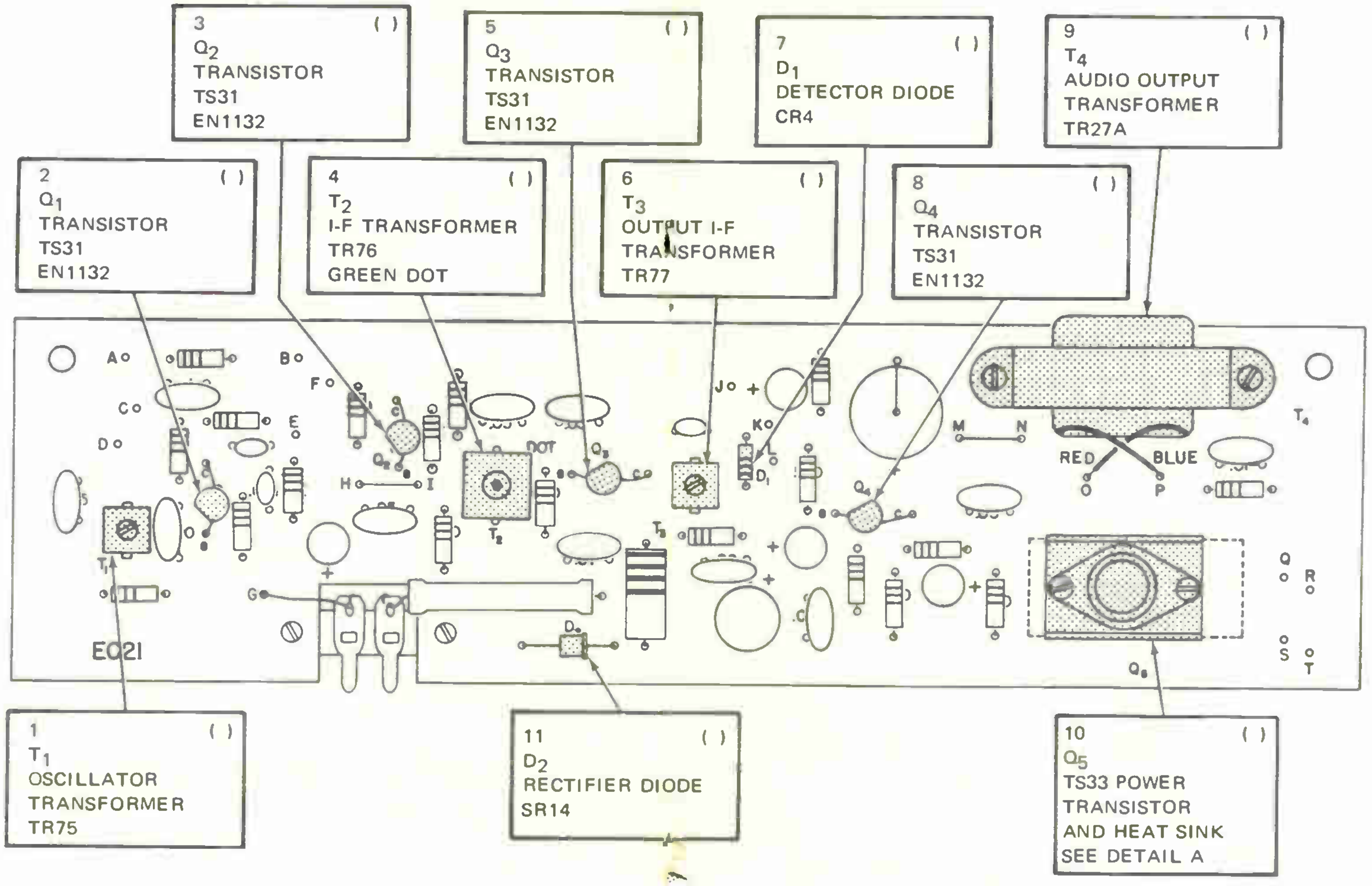
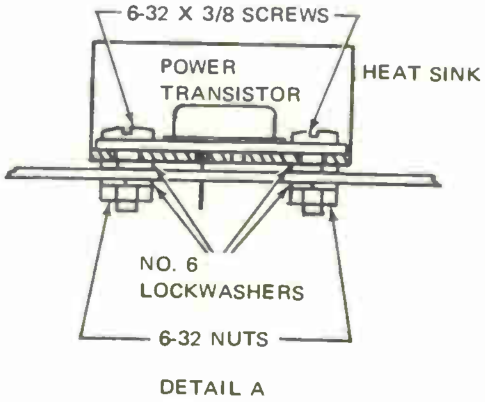


Fig. 8. Installing the transformers, transistors, and diodes on the circuit board.



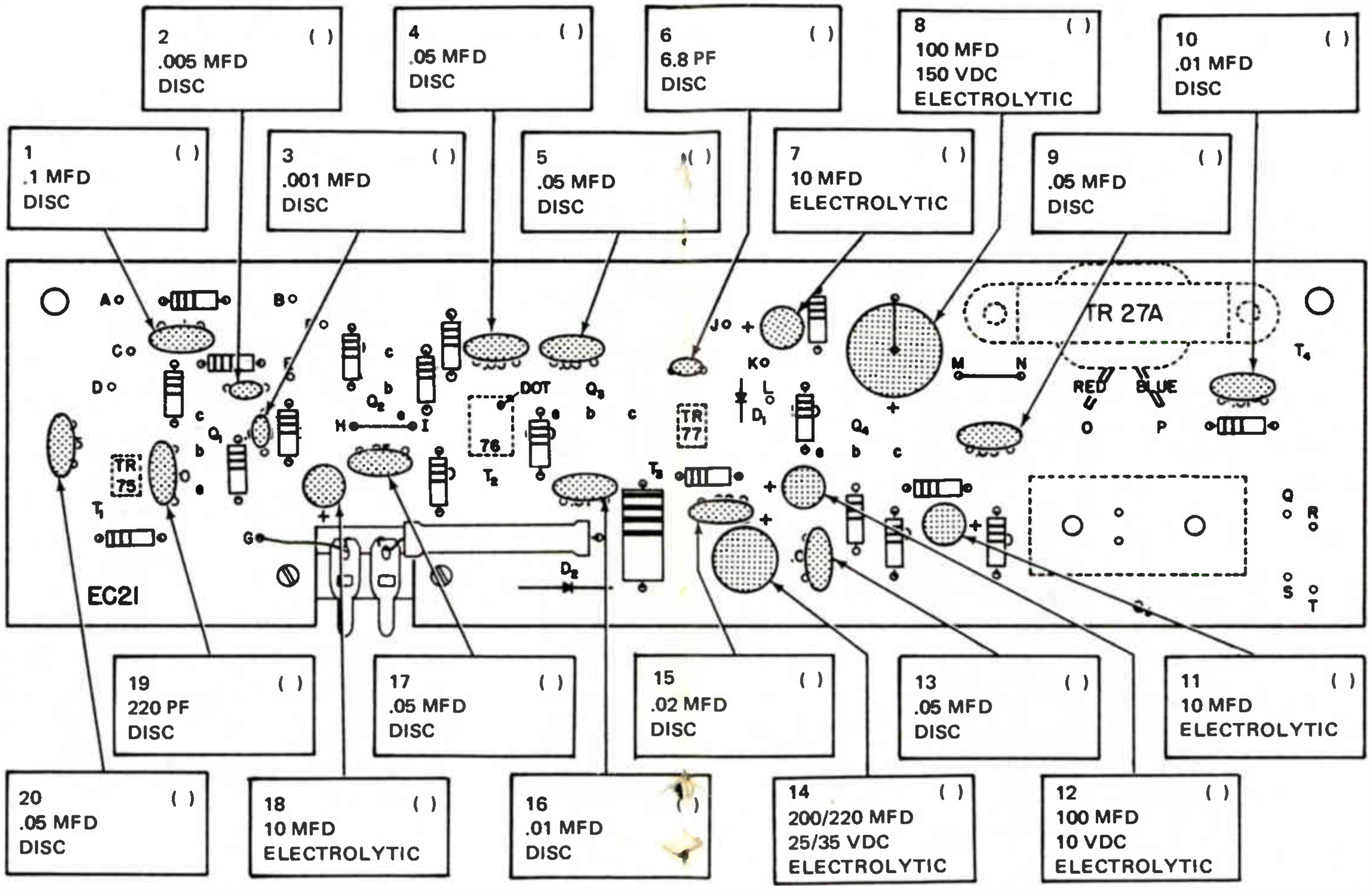


Fig. 7. Installing the capacitors on the circuit board.

These diagrams should be removed from the book so you can refer to them quickly and easily. Carefully open the staples, remove the diagrams, and then close the staples again so the book will not fall apart.

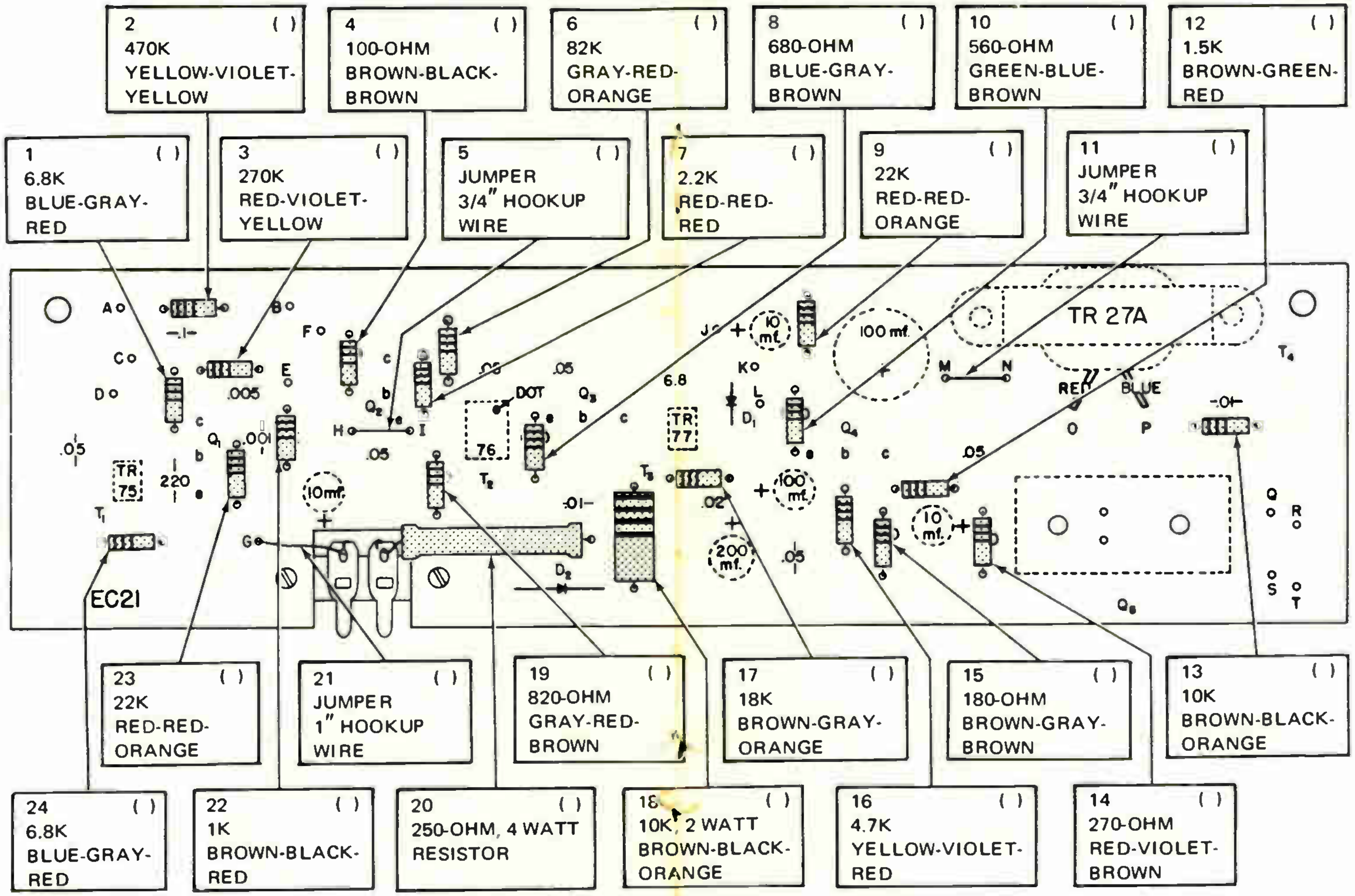


Fig. 6. Installing the resistors on the printed circuit board.

Again examine the schematic diagram of the receiver (Fig. 19) to see how element polarity is applied to a transistor in a circuit. For example, from the schematic you can see that Q_3 is a PNP transistor. Or you can determine the polarity from the transistor symbol. You know that the electrons must flow against the arrow on the emitter symbol. This means that the collector must be negative to force electrons through the transistor against the arrow. Since the collector is negative, the base must also be negative to provide forward bias.

Now look at the schematic of the receiver in terms of taking actual voltage measurements on the elements of transistor Q_3. You clip the ground lead of the meter to a B– point in the circuit. What dc voltage can you expect at the collector of Q_3? From the schematic you see that the collector connects to B– through only a few turns of the transformer, T_3. The dc voltage at the collector will probably read zero volts. But the collector must be negative in relation to the emitter for the transistor to operate.

Therefore we can expect to read a positive voltage at the emitter. If the emitter measures positive, then the collector is negative with respect to the emitter even though the actual collector voltage measured is zero. Next we measure the base voltage. To be forward biased, the base voltage must have the same polarity as the collector.

However, the collector measures zero and the emitter is positive. Therefore, we can expect to measure a positive voltage on the base. As long as the measured voltage is less positive than the emitter, the transistor will be forward biased. The voltage difference between the base and the emitter is usually quite small. In some cases you have to observe the meter needle very carefully to detect the very small difference.

Which voltage measurement will tell us if the transistor is conducting? From the schematic diagram of the receiver, you can see that any current through transistor Q_3 must also flow through the 680-ohm emitter, resistor R_{10}. If this resistor has a drop across it, the transistor must be conducting. Therefore the difference between the B+ voltage and the emitter voltage reading is an indication of how heavily the transistor is conducting.

Some circuits will have a resistor in both the collector circuit and the emitter circuit. Both of these resistors will carry the conducting current of the transistor. The drop across the larger resistor will usually give the best indication of the conduction of the transistor. In some cases, the emitter resistor or the collector resistor may be part of a voltage-divider network. In that case, the drop across the resistor may not be a reliable indication of transistor conduction.

This discussion may seem incomplete to you. Read it again after performing this experiment. In the experiment you will take measurements on transistors with simulated defects. In each case, you should find that the readings on the defective transistor do not meet the requirements presented in the discussion.

Experimental Procedure: For this experiment you will need your operating receiver, meter, and hand tools.

Step 1: To measure the voltages in the circuit of a properly operating transistor stage.

Take the voltage measurements indicated in the table of Fig. 63-2, and record your readings in the spaces provided. Be

	TUNED TO POINT BETWEEN STATIONS		TUNED TO STRONG LOCAL STATION	
	TYPICAL READING	YOUR READING	TYPICAL READING	YOUR READING
B− to Collector	0 VDC	0 V	0 VDC	0
B− to Base	+17.1 VDC	17.5 V	+18.3 VDC	18.0
B− to Emitter	+17.8 VDC	18.0 V	+19 VDC	18.8
Emitter to Base	− .7 VDC	.6 V	− .7 VDC	.58
Drop Across R10	+ .5 VDC	.8 V	+ .3 VDC	.80
B− to B+	+18.3 VDC	18.5 V	+19.3 VDC	19.0

Fig. 63-2. Chart showing typical readings obtained on transistor stage Q_3, with spaces for recording your readings.

sure to check your meter for exact zero before taking each measurement. Estimate the meter reading carefully when the needle indicates between graduations on the scale. On the 30-volt range it is difficult to read the meter accurately to tenths of volts. However, you must read the meter accurately or your readings will be misleading.

The first set of readings in Fig. 63-2 is taken with the receiver tuned between stations. Examine the typical readings. The difference between the B− to base reading and the B− to emitter reading is 17.8 − 17.1 or .7 volt.

In the emitter-to-base column we show a typical reading of −.7 volt. This reading was taken by clipping the common lead of the meter to the emitter and touching the probe to the base (meter set to read −dc on its lowest range). Since the base is more negative than the emitter, the transistor is forward biased. The two values should be the same, but due to the difficulty of reading the scales and meter inaccuracy, the values may not be identical. You can expect similar discrepancies in your readings.

Now compare the first set of readings with those obtained when the receiver is tuned to a strong local station. Observe that B+ is increased by 1 volt with a station tuned in. The reason for this is simple. The received signal produces avc bias that reduced the gain of Q_2 and Q_3. The reduced conduction of these two transistors reduces the B+ current drain. This, in turn, reduces the drop across the 10k-ohm dropping resistor, R_{20}, so the B+ voltage rises.

Notice that the drop across the emitter resistor, R_{10}, decreased by nearly one-half when the station was tuned in. This also indicates that the transistor is passing less current. From the typical readings, there was no readable difference in the emitter-to-base voltage under the two operating conditions. This indicates that it takes only a small change in base-to-emitter voltage to produce a sizable change in transistor current.

Compare your set of readings with the typical readings given. Several factors may cause your readings to be quite different from the typical readings. Line voltage and normal parts tolerances could cause your readings to be considerably higher or lower. Be sure to use your readings for comparison when performing other steps in this experiment.

Step 2: To show typical voltage readings in a transistor circuit when certain elements of the transistor are shorted.

For this step you simulate shorts between the various elements of transistor Q_3 and measure the resultant voltages. In a servicing situation, these defects could be within the transistor or in the external circuitry.

Tack-solder a short piece of hookup wire from the foil at the base of Q_3 to the foil at the emitter of Q_3 to simulate a base-to-emitter short in the transistor. Energize the receiver and measure the voltages on the transistor. Compare your measurements with the readings you recorded for normal operation. The emitter-to-base voltage will, of course, be zero. This means the transistor has no forward bias. The B- to base and emitter will read very nearly the B+ value because the transistor is not drawing current. Likewise, the B+ readings will be very nearly normal.

Measure the drop across R_{10}. A typical reading will be .2 volt. To see why you have current through R_{10}, again examine the schematic diagram. The base-emitter short completes the circuit from B+ through R_{10}, through the short to the base, through part of the secondary winding of T_2 and through R_9 to B-. Current through this circuit produces the voltage drop across R_{10}.

Unsolder and remove the short from the base to the emitter of Q_3. Connect the short from the emitter to the collector. Energize the receiver, and again take voltage measurements. The voltage will, of course, be the same at the emitter and the collector. These two readings (both zero) by themselves would indicate that the transistor does not have the proper operating voltages applied to it.

Next, measure the base voltage. A typical value is about 7 volts, indicating that the transistor is reverse biased. Then measure B+. A typical reading is about 7 volts. Measure a drop of about 7 volts across the emitter resistor, R_{10}.

Now examine the schematic diagram to see why the emitter-collector short produces the voltage readings you observed. The short circuit allows excess current through R_{10}. Since R_{10} is a low-value resistor, it allows enough current to drop B+ to less than half its normal value. If you were servicing this set, you would have to isolate the components to pin down the exact location of the short. For example, the defect could be a shorted capacitor, C_{13}, or an internal emitter-to-collector short in the transistor.

Unsolder and remove the emitter-collector short. Connect the short between the foil at the collector and the base. CAUTION! Do not short the collector-to-base of a transistor circuit unless you are sure that it will not exceed the ratings of the transistor. In your receiver, the emitter resistor of Q_3 limits the current to a safe value. Energize the receiver and again take voltage measurements. The collector and base are at the same potential, so the transistor is forward biased. Measure the emitter-to-base voltage.

A reading of .7 volt is typical, indicating a forward-biased transistor. You may read some small positive voltage from B- to the emitter. B+ again measures very low, about 7 volts, and the drop across R_{10} is about 7 volts.

The preceding readings, if obtained on a defective receiver, would not definitely pinpoint the defect. The excessive drop across R_{10} accounts for the low B+ reading. You would have to isolate components to locate the short. In this case, the base-collector short places a large forward bias on the transistor so that the emitter-collector circuit is almost a short circuit. The transistor conducts heavily, producing a large drop across R_{10} and the resultant low B+ voltage. Unsolder and remove the short that you connected between the collector and the base. Test the receiver for proper operation.

In this step you have investigated the voltage indications of the three possible shorted conditions that might exist within a transistor stage. Voltage measurements at the elements indicate the bias condition and the operating voltages of the transistor. The voltage drop across the emitter resistor indicates the relative amount of current in the transistor circuit. From these tests you can see that, although the voltage tests indicate the presence of a short, you have to remove components and make additional tests to find the exact location of the short.

Step 3: To show typical voltage readings in a transistor stage when certain elements of the transistor are open.

Turn off the receiver and unsolder the collector lead of Q_3 from the foil on the circuit board. Handle the collector lead carefully, as too much flexing of the lead can break it off where it enters the transistor body. Grasp the collector lead with your longnose pliers, heat the foil at the collector connection, and gently pull the collector lead out of the hole. This will simulate an open collector within the transistor.

Energize the receiver and take voltage readings around the Q_3 transistor stage. Compare your readings with those obtained for normal operation. B+ should read normal or slightly above normal. The B- to emitter and B- to base readings should measure approximately the B+ voltage value. A typical emitter-to-base reading is .7 volt, indicating that the transistor is forward biased. However, you will read only a fraction of a volt drop (about .2 volt) across R_{10}, indicating that the transistor is drawing little or no current.

Since your readings indicate a large forward bias and adequate emitter voltage, it is reasonable to assume that either the collector is open internally or there is an open in the collector circuit through the primary winding of T_3. With the receiver turned off, you could use your ohmmeter to confirm the location of the open.

Next, unsolder and remove the base lead connection from Q_3 at the circuit board. Then reconnect and solder the collector lead connection. This simulates an open base in the transistor. Again take voltage readings in the stage. B+ should be slightly higher than normal. The emitter should measure nearly the B+ value, and the base connection (point on the foil where the base is usually connected) should measure something less than the B+ value. The emitter-to-base measures excessively higher than normal, a typical reading being - 1.3 volts. The drop across the emitter resistor, R_{10}, should be zero, since Q_3 is cut off.

The preceding readings definitely indicate a defective transistor. The proper polarity operating voltages are present. The higher-than-normal forward bias should produce transistor conduction. However, the emitter resistor indicates very little transistor current, so the transistor must be defective.

Unplug the receiver, unsolder and remove the emitter lead of Q_3. Then reconnect and solder the base lead to the circuit board. This simulates an open emitter in the transistor. Energize the receiver and again take voltage readings on the stage. B+ should read normal or slightly high.

The point on the foil where the emitter usually connects reads the B+ value and the base reads less than B+. The emitter-to-base reads about -1.5 volts, indicating very large forward bias. However, the drop across the emitter resistor, R_{10}, reads zero, indicating no current through the transistor. It follows then that the transistor or the emitter-collector circuit of the transistor must be open.

Turn off the receiver. Reconnect and resolder the emitter leads of Q_3. Test the receiver for proper operation.

Instructions for Statement 63: For this statement you short-circuit two elements of the audio driver transistor, Q_4, and observe the results. Simply tack-solder a short piece of hookup wire from the foil at the base of Q_4 to the foil at the emitter of Q_4. Energize the receiver, observe its operation, take voltage readings or other tests, as necessary, to answer the statement.

Turn the receiver off. Unsolder and remove the short that you connected from the base to emitter of Q_4. Test the receiver to be sure that it is operating properly.

Statement No. 63: When I shorted between the emitter and the base of the audio driver transistor, Q_4,

(1) the receiver operated almost normally but with reduced volume and some evidence of distortion.

(2) the receiver operated only on strong stations and the sound was garbled.

[✓ *(3)*] *the receiver produced no sound because the short circuit back-biased the audio driver stage.*

EXPERIMENT 64

Purpose: To show the effects of leaky bypass capacitors; and

To show how to locate them with an ohmmeter and with a voltmeter.

Introductory Discussion: The dc power supply line is maintained at signal ground potential by the use of bypass capacitors. Signals are bypassed around the power supply by providing a low impedance path (low impedance to the ac signals) from the dc power line to ground. These bypass capacitors are often electrolytic capacitors that tend to develop leakage. When the dielectric of the capacitor allows direct current to flow through the capacitor, we have leakage.

This condition can vary from a few microamps of leakage to a direct short through the dielectric of the capacitor. We can simulate a leaky capacitor by paralleling it with a resistor. The size of the resistor can be varied to simulate any degree of leakage through the capacitor.

A leaky bypass capacitor usually upsets the dc operating voltages in the receiver. A small amount of leakage will go unnoticed and have negligible effect on the operation of the receiver. In fact, most electrolytic capacitors will normally have some small leakage current. However, when the leakage becomes high, the condition is usually progressive. That is, the receiver may operate quite normally when first turned on, but when the set comes up to operating temperature the leakage increases. The excessive leakage current causes further deterioration of the dielectric and eventually the capacitor will short-circuit.

In this experiment, we limit the simulated leakage to values that will not damage other parts in the receiver. For example, excessive leakage through C_{23} could damage the power supply rectifier diode, D_2. This is a common servicing situation. A shorted filter capacitor overloads the rectifier, causing it to fail. Therefore, whenever you have to replace a rectifier diode, check to see if the filter capacitor is shorted. Otherwise, you may ruin the replacement diode.

Experimental Procedure: For this experiment you will need the operating receiver, the voltmeter, and the following:

1 10k-ohm resistor
1 6.8k-ohm resistor
1 2.2k-ohm resistor

Step 1: To show the effects of leakage in the B++ filter capacitor.

For this step you parallel the 100 mfd filter capacitor, C_{23}, with a 6.8k-ohm resistor. This arrangement exceeds the wattage rating of the resistor, so it will overheat if the receiver is left energized for even a few minutes. Therefore, leave the receiver energized only long enough to take the indicated measurements or observations; otherwise the 6.8k-ohm resistor will burn up.

	NORMAL READINGS	READINGS WITH 6.8K IN PARALLEL WITH C23	
B- to B++ VOLTAGE			
B- to B++ RESISTANCE			

Fig. 64-1. Chart for recording readings for Step 1.

Turn the receiver on and test it for proper operation. Tune in a station and adjust the volume for normal listening. Measure the B++ voltage, and record your reading in the Normal column in Fig. 64-1. Unplug the receiver from the line and measure the resistance between B++ and B–. Record your reading in the Normal column in Fig. 64-1.

Tack-solder the 6.8k-ohm resistor from the B++ foil to the B- foil. Again, measure the resistance from B++ to B- and record your reading in Fig. 64-1.

Set up your meter to measure +dc voltage on the 120-volt scale. Connect the line cord to the receiver, listen to the station, and quickly measure the B++ voltage. Turn off the receiver. Feel the body of the 6.8k-ohm resistor with your fingers. You will probably find it warm, even though the receiver was on for only a short time. Record your voltage reading in the space provided in Fig. 64-1.

Compare the readings you recorded in Fig. 64-1. Paralleling C_{23} with the 6.8k-ohm resistor increased current drain from the power supply. The parallel path caused the resistance to drop to approximately one-fourth of what it was originally. Likewise, the power supply voltage decreased, but only a small amount. You probably noticed little or no change in the operation of the receiver.

Consider what would have happened if the simulated leakage had occurred inside the capacitor. The same heat would be generated by the current through the resistance. The capacitor would probably overheat and fail completely. With less leakage, the receiver would continue to operate.

When servicing a receiver in which you measure lower than normal B+ voltage, always consider the possibility of leakage current. Check to see if the capacitor or other components in the circuit overheat. Then use resistance measurements to locate the leakage path in the circuit.

In a battery-operated transistor receiver, leakage seldom causes overheating. The complaint is more likely to be short battery life. Some reduction in volume or sensitivity may go unnoticed, but the increased drain on the battery can greatly reduce the life of the battery.

Step 2: To show the effects of leakage in the B+ filter capacitor, C_{22}.

For this step you parallel capacitor C_{22} with a 2.2k-ohm resistor to simulate leakage in the capacitor. Examine the schematic diagram of the receiver to see if you can predict the results.

Turn the receiver to a local station, adjust the volume for normal listening, and unplug the line cord. Tack-solder a 2.2k-ohm resistor from the foil at B– to the foil at B+, which is also the positive terminal of capacitor C_{22}. This connection simulates internal leakage in the capacitor. Connect the line cord of the receiver to the ac line and note any change in the reception of the station. Measure the B+ voltage and compare your readings with normal B+ voltage. Also measure B++ voltage to see if it has changed from normal.

Unplug the receiver and measure the resistance between B– and the B+ line. A typical reading is about 1.5k-ohms, with the 2.2k-ohm resistor in parallel with C_{22}. Unsolder the 2.2k-ohm resistor and again measure the resistance. A typical reading is about 10k-ohms.

From these tests, you can see that a sizable leakage is necessary to produce a noticeable change in the operation of the receiver. Even though the B+ voltage decreased by almost one-third, the receiver still operates. In a servicing situation the complaint might be reduced volume or reduced sensitivity.

Your voltage measurements would indicate that excessive current was being drawn from the B+ line; also your resistance measurements would indicate lower than normal resistance on the B+ line. Further voltage measurements on the circuit branches from the B+ line would help isolate the defect. However, you would have to isolate components and take more resistance measurements before you could definitely determine where the leakage exists in the circuit.

Step 3: To show the effects of leakage in the rf bypass capacitor, C_5.

Ceramic disc capacitors seldom develop leakage. This is particularly true in transistor radios where the supply voltages are low. However, leakage or complete short circuits can and do occur. In this step we investigate the effects of a leaky or shorted capacitor, C_5. From the schematic diagram, C_5 appears to be simply an rf bypass capacitor that completes the path for the ac signal in the tank circuit of the local oscillator.

Tune the receiver to a local station and adjust volume for normal listening.

Unplug the receiver and tack-solder a 6.8k-ohm resistor on the foil side of the board in parallel with C_5. Energize the receiver and note the effect, if any, on the receiver operation.

Turn off the receiver and remove the 6.8k-ohm resistor that you paralleled with C_5. In its place, tack-solder a piece of short hookup wire to simulate a shorted capacitor, C_5. Again, test the operation of the receiver. Next, measure the dc voltage from B- to the frame of the tuning capacitor. Six volts or so is a typical reading.

From this step of the experiment, you can see that a leaky or shorted C_5 does not affect the operation of the receiver. To see why C_5 is in the circuit, again examine the schematic diagram of the receiver.

As we stated before, C_5 completes the circuit for the local oscillator tank circuit consisting of the primary of T_1 and the oscillator section of the tuning capacitor. The other function of C_5 is to isolate the capacitor frame from the circuit for safety reasons. As you know, B- connects to one side of the ac power line.

If the capacitor frame were connected to B-, the capacitor mounting plate, the tuning capacitor shaft and the volume control shaft would be "hot". If a knob were removed from the operating receiver, a person could receive a dangerous electrical shock. To prevent this, the network consisting of R_5 and C_8 is used to isolate the metal part from B-.

Consider what could happen if a direct connection were used instead of C_5. A shorted transistor, Q_1, would connect B- through terminals 5 and 3 of the primary of T_1 directly to the metal frame of the tuning capacitor. The metal shafts would again be "hot," presenting a dangerous situation.

Unsolder and remove the short that you connected across C_5. Test the operation of the receiver.

Step 4: To show the effects of leakage in the emitter bypass capacitor, C_{13}.

Tack-solder a 6.8k-ohm resistor from the foil at the emitter of Q_3 to B-. This connection places a resistor in parallel with C_{13} and simulates a leaky capacitor. Energize the receiver and test its operation. Take voltage readings on the base and emitter of Q_3. You should find that both elements are almost exactly the same potential.

Examine the schematic of the receiver to see the effect of leakage in C_{13}. Resistor R_{10} and the leakage through C_{13} form a voltage divider that lowers the positive voltage at the emitter of Q_3. The base voltage must be negative (less positive) in respect to the emitter to provide forward bias for the transistor. The base voltage for Q_3 is set by the conduction of Q_2. With the Q_3 emitter voltage lowered, the transistor remains cut off and the receiver does not operate.

Unsolder and remove the 6.8k-ohm resistor that you had in parallel with C_{13}. Tune in a station and adjust the volume for normal listening. Temporarily shunt a 10k-ohm resistor across capacitor C_{13}. This simulates a smaller amount of leakage through C_{13}. Listen for a change in volume. It should decrease a noticeable amount. Remove the 10k-ohm resistor and test the receiver for normal operation.

From the preceding tests you can see that leakage in C_{13} upsets the dc operating voltages for the transistor. A small amount of leakage will produce reduced sensitivity, and a large amount of leakage will make the set completely inoperative. Careful voltage readings will help point to the cause of the trouble, but you would have to isolate components and take resistance measurements to pinpoint the defective components.

Instructions for Statement 64: For this statement you investigate the effect of simulated leakage in the emitter bypass capacitor of the audio driver stage, Q_4.

On the foil side of the board, tack-solder a 2.2k-ohm resistor to the foil at the terminals of the 100 mfd electrolytic capacitor, C_{18}. This connection simulates leakage through the capacitor. Energize the receiver and test its operation. Examine the schematic diagram of the receiver, take voltage measurements and other tests, as necessary, to answer the statement.

Unsolder and remove the 2.2k-ohm resistor that you tack-soldered in parallel with C_{18}. Test the receiver for normal operation.

Statement No. 64: When I simulated leakage in the emitter bypass capacitor, C_{18}, of the audio driver stage,

(1) the receiver operated normally, because C_{18} is already paralleled by a low value resistor.

(2) the receiver operated, but the volume was reduced and the sound was garbled.

(3) the receiver produced no sound, because the changed operating voltages back-biased the audio driver transistor, Q_4.

EXPERIMENT 65

Purpose: To demonstrate common causes of low sensitivity in a transistor radio receiver; and

To demonstrate forward-acting avc.

Introductory Discussion: A familiar complaint on transistor receivers is loss of sensitivity. The complaint may be that the receiver will no longer pick up a certain station or a station is not as loud as it used to be. In battery-operated receivers, the first thing to try is a new battery. Low battery voltage will usually show up first as loss of volume or reduced sensitivity. In other cases, the set may perform fairly well until the battery voltage becomes so low that the local oscillator drops out. In this case, the complaint will be a dead receiver.

Loss of sensitivity can be caused by faulty operation of any of the signal-handling circuits in the receiver. Good receiver sensitivity is the ability of the receiver to pick up weak stations. Therefore, the condition of the audio section of the receiver does not affect the sensitivity. In practice, however, a weak audio stage makes the receiver appear to have low sensitivity.

The avc circuits in transistor receivers have many variations. In general, a voltage from the second detector is fed back to control the gain of the i-f stages. The avc voltage may affect one or more stages in the receiver. The usual avc circuit uses what is called reverse-acting or reverse-biasing avc.

That is, the avc voltage fed back from the detector is of the correct polarity to reverse-bias the i-f stages. The stronger the received signal, the larger the reverse bias, which results in reduced current and reduced gain of the controlled stages.

Another type of avc circuit uses what is called forward-acting avc. The polarity of the avc voltage increases the conduction of the controlled stages. When you first trace out a forward-acting avc circuit, you may suspect that the detector diode is reversed. The forward-acting polarity is intentional, however.

The increased forward bias causes the transistor to draw increased current and lowers the emitter-to-collector voltage, causing reduced gain. You can think of the transistor as being operated near the saturation point on the transfer curve, which causes reduced gain. In this experiment you vary the bias on an operating i-f stage to simulate circuit conditions for forward-acting avc.

Experimental Procedure: For this experiment you will need your operating receiver, voltmeter, hand tools, and the following parts:

1 2200 pf disc capacitor
1 1.5 volt D cell battery
1 1k-ohm potentiometer (PO7)
1 470-ohm resistor

Step 1: To show the effects of an open circuit in the loop antenna of your receiver.

Unsolder and remove the loop antenna connection to the rf section of the tuning capacitor. Energize the receiver and test its operation. If you have strong local stations, you should be able to receive some of them fairly well. Touch your hand to the bare end of the antenna wire that you disconnected from the tuning capacitor. This should improve reception. Solder the antenna connection back in place to the rf tuning capacitor terminal, and test the receiver for normal operation.

A broken antenna wire is a common defect, especially in portable transistor receivers. The customer may break a connection by careless handling while changing the battery. Careful visual inspection will usually reveal the location of the break. Suspect a break in the antenna wires whenever touching the leads greatly improves reception.

Normally, the antenna circuit is tuned to resonance at the frequency of the incoming rf signal. Therefore, when you touch the terminals, your hand capacitance will tend to detune the circuit and decrease the sensitivity. If touching the circuit improves the reception, as it does when the circuit is broken, your body is providing additional signal pick-up.

This test is not always valid. The antenna tank circuit may not track perfectly at all frequencies across the band. Therefore, you may get some improvement in reception when you touch the circuit, even though the circuit is operating correctly.

Step 2: To show the effects of an open circuit in the secondary winding of the loopstick antenna.

Unsolder and remove the antenna connection from hole E on the circuit board. Energize the receiver and attempt to tune in a station. You should not be able to pick up any stations.

Examine the schematic diagram of the receiver to see why the set is completely dead. Notice that the local oscillator signal is coupled through C_7 and through the secondary winding of the loop antenna to the base circuit of the mixer stage, Q_2. When you open the secondary winding of the loop antenna, you effectively disconnect the local oscillator signal from the mixer stage so that the set is inoperative. Also, the base bias voltage is supplied to the base of the transistor through the secondary winding. When the secondary winding is open, so is the base circuit.

Tack-solder a short piece of hookup wire from the foil at hole E to the foil at the base connection of Q_2. This connection provides a path for the local oscillator signal to reach the base of Q_2.

Energize the receiver and again test its operation. You should be able to receive at least one strong local station. If necessary, touch your hand to the free end of the wire that you disconnected from hole E to improve reception.

Turn off the receiver. Unsolder and remove the short that you connected from the foil at hole E to the base of Q_2. Reconnect and solder the antenna wire at hole E. Test the receiver to make sure that it is operating properly.

In many receivers, the oscillator and the mixer functions are combined in the same stage so that opening the loop secondary will not remove the oscillator signal from the mixer. In these receivers, an open secondary in the loop antenna will simply cause reduced sensitivity.

Step 3: To show the effects of a shorted detector diode on the operation of the receiver.

Tack solder a short piece of hookup wire to the foil at each end connection of the diode detector, D_1. This connection simulates a direct short in the detector diode. Turn the receiver on and test its operation. You may be surprised to find that you are able to receive one or more strong local stations.

Since the detector diode is effectively out of the circuit, detection must be taking place elsewhere. With the diode shorted, the i-f signal is coupled through C_{16} to the base circuit of the audio driver Q_4. Detection takes place in the base-emitter junction of the transistor and the detected audio signal is reproduced in the collector circuit. Some of the i-f signal is attenuated in the detector filter circuit.

Unsolder and disconnect one lead of the .02 mfd filter capacitor, C_{15}. Again test the receiver operation. It should exhibit volume and sensitivity almost equal to that obtained by the diode detector circuit.

Reconnect and resolder the disconnected lead of capacitor C_{15}. Unsolder and remove the short you tack-soldered in parallel with diode detector D_1. Test the receiver for normal operation.

Ordinarily you expect a diode to fail completely when it goes bad. This step shows that you may get detection even if the diode shorts. Thus if you have low sensitivity or low volume, do not overlook the possibility that the diode has failed and some detection is taking place in the base-emitter junction of the first audio stage.

Step 4: To show the effects of a detuned i-f stage on the operation of the receiver.

For this step you detune the i-f transformer by bridging a capacitor across the windings. The added capacitance changes the resonant frequency of the circuit and reduces the gain of the stage. You can either tack-solder the capacitor in place, or simply hold the body of the capacitor between your fingers and touch the leads to the indicated terminals of the transformer.

Energize the receiver, tune to a local station and adjust the volume for normal listening level. Bridge a 2200 picofarad capacitor between terminals 3 and 4 of i-f transformer T_2. Note the change in level of the reproduced signal. Repeat the above procedure for terminals 1 and 2 of transformer T_2, terminals 1 and 2 of transformer T_3, and finally for terminals 3 and 4 of transformer T_3. Remove the capacitor and test the receiver for normal operation.

Paralleling the 2200 pf capacitor with a winding of an i-f transformer detunes the circuit and greatly reduces the gain of that stage. However, the receiver is still able to process strong local signals. You probably notice that shunting the 3-4 winding of T_3 produced only a small loss of signal.

The secondary winding of transformer T_3 is at a low impedance, and it is not tuned. The loss of signal is simply caused by the added capacitance shunting some of the signal that would otherwise go to the detector diode.

Most service situations related to detuning of the i-f occur when someone moves the tuning adjustments on the i-f transformers. This calls for either touch-up alignment or complete realignment of the receiver. In a later experiment you will work with alignment problems.

Step 5: To demonstrate how forward bias, simulating forward-acting avc, causes reduced gain of an i-f stage.

For this step you prepare a variable bias supply to control the gain of the i-f transistor, Q_3. Construct the circuit shown in Fig. 65-1B. (Fig. 65-1A shows terminal identification.) Connect a 470-ohm resistor from the positive terminal of the 1.5-volt cell at terminal 3 of your 1k-ohm potentiometer, PO7.

Connect a piece of hookup wire from the negative terminal of the cell to terminal 1 of the pot. Connect a 12" piece of hookup wire from terminal 3 of the pot to the foil at the emitter of Q_3. Connect a 12" piece of hookup wire from terminal 2 of the pot to the foil at the junction of R_4 and R_9 on the circuit board. This point is also the junction of terminal 2 of T_2 and one lead of C_{12}.

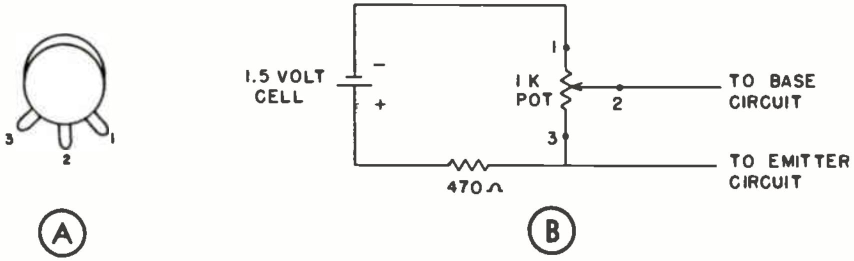


Fig. 65-1. (A) terminal identification; (B) variable bias supply circuit.

These connections will enable you to apply a variable dc bias between the base and emitter of Q_3. With the pot turned all the way clockwise, the difference in potential between the emitter and the base will be approximately zero volts. Rotating the pot counterclockwise applies a negative voltage to the base (in respect to the emitter). The negative voltage forward-biases the transistor.

Energize the receiver and tune to a station. Connect your meter between the emitter and the base of Q_3 so you can read the actual bias on the transistor. Set the meter to read -dc on the lowest scale. Adjust the bias for about -.6 volt and carefully tune in a station. Rotate the bias pot over its full range and note the range of bias voltages that gives reception. The transistor, Q_3, will be completely cut off at a bias voltage somewhere between -.4 and -.5 volt. Maximum gain will be obtained with a bias near -.6 volt.

As you make the bias more negative, the gain decreases. Further rotation of the pot will not produce a corresponding change in bias, because the increased base current produces a voltage drop in the pot circuit, limiting the bias voltage.

The i-f stage may go into oscillation as you increase the forward bias. The neutralizing values are selected for normal operating conditions. With increased forward bias, capacitor C_{14} provides a feedback path that may produce oscillations. Unsolder and disconnect one lead of C_{14} to minimize the tendency to oscillate. Also you can turn the slug adjustment on T_3 one-quarter turn to help prevent oscillation.

Measure the emitter-to-collector voltage change as you vary bias over the full range. With normal operating bias, the emitter-to-collector voltage will measure nearly B+ voltage. This indicates that the transistor is drawing only a small current and only a small amount of voltage is dropped across the emitter resistor, R_{10}. As you increase the forward bias, the transistor current increases and the emitter-to-collector voltage decreases. This decrease in emitter-to-collector voltage helps to explain why the gain decreases as the forward bias is increased.

A forward-acting avc circuit controls the stage gain in the same way as we have shown. The controlled stages have a fixed bias that produces maximum gain. When a station is tuned in, the detector produces avc voltage that is applied to the controlled stages. Polarity of the avc voltage is such that it increases the forward bias on the controlled stages. As you saw in this step, the increased forward bias caused decreased emitter-to-collector voltage and reduced gain for the stage.

Unsolder and remove the leads that you connected from the bias pot to the base circuit and emitter circuit of the board. Unsolder and remove the flashlight cell and other parts that you had connected to the bias pot. Reconnect and solder the disconnected lead of capacitor C_{14}. Energize the receiver and test for proper operation. If necessary, readjust the core of transformer T_3 for maximum output.

Instructions for Statement 65: For this statement you place a capacitor across a part of the secondary winding of i-f transformer T_2 and observe the effect on the operation of the receiver.

Tune the receiver to a station and adjust the volume for normal listening.

Tack-solder a 2200 pf capacitor between terminals 2 and 6 of transformer T_2. Energize the receiver and test its operation. Then answer the statement.

Unsolder and remove the 2200 pf capacitor you connected from terminal 2 to terminal 6 of T_2. Test the receiver for normal operation.

Statement No. 65: When I connected a 2200 pf capacitor from terminal 2 to terminal 6 of i-f transformer T_2,

[✓ *(1) the receiver operated normally, with no noticeable change in sensitivity.*]

(2) the receiver operated, but with greatly reduced sensitivity.

(3) the receiver did not operate at all, because the capacitor shunted the small signal normally applied to the base of Q_3.

EXPERIMENT 66

Purpose: To demonstrate typical causes of hum in a line-operated transistor radio receiver.

Introductory Discussion: The hum produced by the 60 Hz line voltage is normally associated only with line-operated receivers. One of the advantages of battery-operated receivers is the freedom from the hum and noise that originate from the power line.

Hum can get into the signal path in two different ways. Insufficient filtering in the B+ line allows an audible sound signal to be produced in the audio circuits of the receiver. If the hum signal gets into the signal path at one of the low signal level stages, the hum signal will be amplified along with the desired signal. Or the 60 Hz signal can modulate any rf stage of the receiver and be detected by the second detector.

This condition can occur even in a battery-operated receiver. If the receiver is in close proximity to a power line, the sensitive rf section of the receiver may pick up enough 60 Hz signal to modulate an rf stage and produce an audible hum.

Noise on the power line may be picked up by either a battery-operated or line-operated receiver. The noise may be described as hum, because it usually varies at the 60 Hz line rate. To hear this noise, simply tune a receiver between stations, turn up the volume control and hold a line cord near the loopstick antenna. The noise will come through loud and clear.

Neon or fluorescent lights are another source of similar noise. Line-operated receivers sometimes have noise filters in the line circuit to minimize this source of noise. The amount of noise on the power line varies with locations. Very little noise is usually present in residential areas, whereas in industrial areas the power lines are usually very noisy.

Experimental Procedure: You will need your operating receiver, voltmeter, hand tools and the following parts:

1 10k-ohm resistor
1 2.2k-ohm resistor
1 .001 mfd capacitor
1 .005 mfd capacitor

Step 1: To show the effects of high resistance in the B++ filter capacitor.

For this step you will simulate the conditions of a filter capacitor that has developed series resistance. A capacitor with this defect is also described as one having a poor power factor. Unsolder and remove the jumper that is connected between holes M and N on the circuit board.

In its place, tack-solder a 10k-ohm resistor. Energize the receiver and test its operation. The hum is clearly audible even with the volume control turned to minimum. The program material will sound garbled and the set will exhibit reduced sensitivity. Measure B++ and B+ voltages. Typical values are 65 volts and 10 volts. This large reduction in power supply voltage accounts for the reduced sensitivity and garbled sound.

The above symptoms always point toward a defective filter capacitor. The symptoms are the same if the capacitor develops reduced capacitance. The fact that the hum is present even with the volume control at a minimum is the clue to power supply trouble, and the capacitor is the most likely component to be defective.

Step 2: To show the effect of a small resistance in the filter capacitor.

In this step you change the size of the resistor in series with the capacitor to simulate a small reduction in capacitance or a small series resistance in the capacitor.

Unsolder and remove the 10k-ohm resistor you tack-soldered from hole M to N of the circuit board. In its place tack-solder a 2.2k-ohm resistor. Energize the receiver and test its operation. Turn the volume control to minimum and listen for hum. You may have to tune between stations and place your ear close to the speaker to hear the hum. On a local station at normal listening levels, the operation may seem quite normal. Turn up the volume and listen for distortion. Measure the B++ and B+ voltage. They should measure low.

This step illustrates the effect of only a small loss of capacitance in the filter capacitor. The operation of the set is marginal. The customer's complaint may be "garbled sound," "reduced sensitivity," "noise," or "hum." A careful listening test should make you suspect the power supply.

When you measure B++ and turn up the volume, you should notice that the meter needle varies with sound. This also is an indication that the power supply is unable to furnish the required current to the output transistor. Again the filter capacitor is the most likely component to be defective.

Unsolder and remove the 2.2k-ohm resistor you tack-soldered from hole M to hole N on the circuit board. In its place, install the original jumper. Test the receiver for proper operation.

Step 3: To show the effect of an open filter capacitor, C_{22}, in the B+ power supply line.

To simulate an open B+ filter capacitor, C_{22}, unsolder and remove the capacitor from the circuit board. To do this, grasp the body of the capacitor and pull gently while you heat the connection on the foil side of the board. This takes a little patience. Each time you melt the solder on a connection, the lead will "give" about 1/16". Then heat the other connection until that lead moves. Alternately heat the connections and pull on the capacitor until you work out the leads and the capacitor comes free. Use a toothpick or a paper clip wire to clear the solder from the holes so that they will be ready to receive the capacitor wires when you reinstall the capacitor.

Energize the receiver and test its operation. A distinct hum is audible even at minimum volume. You may be surprised that the hum level is so low with the filter capacitor removed. When you tune in a station and keep the volume low, the set may appear to function almost normally. Measure the B+ voltage. It should be about normal. The condition of C_{22} does not affect the value of B+ as did the input filter capacitor, C_{23}.

Switch the meter to measure ac on a low range and turn up the volume. As you can see, the lack of filtering allows signals to develop on the B+ line across the 10k-ohm dropping resistor, R_{20}. Tune across the band with the volume control wide open. The set will squeal and sputter. Feedback paths through the unfiltered common power supply line is causing oscillation. In some places the oscillations are so strong that the audio is completely drowned out.

When troubleshooting a receiver with this condition, try paralleling the suspected capacitors with a good capacitor. You usually have more than one capacitor in the power supply that could be causing the trouble. The capacitors may be hard to remove or be of odd sizes. If you parallel a suspected capacitor with a good one, a change in operation of the receiver will indicate that the capacitor is defective.

The test capacitor need not be exactly the same size. For example, a 50 or 100 mfd capacitor in parallel with an open 200 mfd capacitor, C_{22}, would improve the operation enough to prove that C_{22} was open. To effect the repair you would, of course, obtain the correct value capacitor for replacement.

Install the 200 mfd capacitor, C_{22}, in its place on the circuit board. Be careful to remove any globs of solder from the leads of the capacitor. If solder makes the leads oversized, it will be difficult to get them through the mounting holes. Be sure to observe the capacitor polarity. Solder the leads in place to the foil. Test the receiver for proper operation.

Step 4: To demonstrate how a 60 Hz line voltage can modulate an rf stage and produce hum.

Unplug the receiver and tack-solder one lead of a .001 mfd capacitor to the interlock terminal where it connects to the 250-ohm, 4-watt resistor, R_{21}. Tack-solder the other lead of the .001 mfd capacitor to the foil at the junction of R_6 and R_8. From the schematic diagram of the receiver, you can see that this is also the point where the oscillator signal is injected into the base circuit of Q_2.

Energize the receiver and test its operation. Tune to the weakest available station and listen to the quality of the program material. It will probably sound garbled and you should hear a noticeable hum signal. If you are in a noisy (electrical noise on the power line) location, the hum may be masked by power line noise. Or the line noise may appear to vary at the line frequency. With the volume turned up, the hum should be quite noticeable.

In this step you coupled the line voltage through a .001 mfd capacitor to the base circuit of the mixer transistor, Q_2. This connection caused a 60 Hz signal to be mixed with the rf and the local oscillator signal. Also the noise on the power line is coupled into the signal path. This step does not illustrate a practical defect that would occur during servicing, but it does enable you to recognize the symptoms when a condition develops where the line voltage modulates an rf stage in a receiver.

Unplug the receiver, unsolder and remove the .001 mfd capacitor that you tack-soldered from the foil at the junction of R_6 and R_8 to the power line terminal. Test the receiver for proper operation.

Instructions for Statement 66: For this statement you will observe the effect of coupling 60 Hz line voltage into the base circuit of the i-f transistor, Q_3. Unplug the receiver and tack-solder one lead of the .005 mfd capacitor to the interlock terminal where it connects to the 250-ohm, 4-watt resistor, R_{21}. Tack-solder the other lead of the .005 mfd capacitor to the foil at the junction of R_9 and C_{12}. Energize the receiver and test its operation, as necessary, to answer the statement.

Unplug the receiver. Unsolder and remove the .005 mfd capacitor that you had connected from the foil at the junction of R_9 and C_{12} to the power line. Energize the receiver and test it for proper operation.

Statement No. 66: When I coupled the 60 Hz power line voltage through a .005 mfd capacitor to the base circuit of the i-f transistor, Q_3,

(1) the receiver operated normally except for a little more noise.

(2) a loud hum was present as long as the receiver was on, and the hum volume did not change with the setting of the volume control.

[✓ *(3) the receiver produced garbled sound with hum and noise.*]

EXPERIMENT 67

Purpose: To show common causes of oscillation and how to locate them.

Introductory Discussion: The high gain stages and compact construction of transistor receivers makes oscillation a common complaint. As you know, a high gain circuit will tend to oscillate whenever energy from the output is fed back into the input. The requirements for oscillation are simple. The energy fed back must be of the proper phase to aid the signal producing the output and the circuit must have sufficient gain to overcome the losses in the circuit.

Since a receiver has many high gain stages, many opportunities for oscillation exist. The common power supply offers one possible feedback path between the output and the input of stages. For example, in a previous experiment, you saw how lack of filtering in the power supply produced oscillation.

The tuned stages in the receiver are particularly susceptible to oscillation. Since the i-f amplifier is tuned to a single frequency, it produces very high gain at that frequency. Even a rather poor feedback path is capable of coupling enough energy from output to input to produce oscillation.

In compact receivers where the parts are closely spaced, the close proximity of a part in an output circuit to a part in an input circuit can couple enough energy to produce oscillation. For this reason, when making repairs you are cautioned to position replacement parts in the same place as the original part. This condition does not exist on your receiver, because the parts are spread out and their position is relatively fixed by the circuit board mounting holes.

Oscillation can occur in high-gain audio stages of a receiver. The frequency of oscillation may vary from only a few Hertz to well above the audio range. The exact frequency at which the circuit oscillates is often determined by the R-C time constant of the feedback path.

The avc circuit of a receiver can provide a feedback path that produces oscillation. The avc circuit varies from receiver to receiver; but in general, a voltage from the output of the second detector is fed back to one or more i-f stages. The avc voltage is filtered, so it is dc that varies in amplitude with signal strength. The circuit has a long time constant compared to changes in signal strength.

A defect in the avc circuit can cause very low frequency oscillation (motorboating) or very high frequency oscillation. Insufficient filtering on the avc line can allow an i-f signal from the output to be fed back to an earlier stage and cause high frequency oscillation. Motorboating can result from a defect in the avc line that produces an extremely long time constant.

In this experiment you simulate defects that can produce oscillation. In some steps you provide feedback paths to produce oscillation so you can recognize the symptoms.

Experimental Procedure: For this experiment you will need your receiver, voltmeter, hand tools, and the following:

1 27 pf disc capacitor
1 1.2k-ohm resistor
1 .001 mfd disc capacitor
1 .005 mfd disc capacitor

Step 1: To demonstrate oscillation in the audio stages of the receiver.

Turn off the receiver and tack-solder a .001 mfd capacitor from the collector of Q_5 to the foil at the base of Q_4. Energize the receiver and test the operation. Vary the setting of the volume control to see the effect on the tone of the audio oscillation.

Unsolder and remove the .001 mfd disc capacitor that you tack-soldered from the base of Q_4 to the collector of Q_5. In its place, tack-solder a .005 mfd capacitor. Energize the receiver and note the lower frequency of the audio oscillation. From this you can see that the R-C time constant of the feedback circuit affects the frequency of oscillation.

If you phase a signal through the two-stage audio amplifier you will find that the output of the collector of Q_5 is in phase with the signal at the base of Q_4. Therefore, when you connect these two points with a capacitor, the circuit oscillates.

Unsolder and remove the .005 mfd capacitor that you connected from the collector of Q_5 to the base of Q_4. Test the receiver for proper operation.

Step 2: To demonstrate the symptoms of oscillation in an i-f stage of a receiver.

On the foil side of the board, tack-solder a 27 pf capacitor in parallel with the 6.8 pf capacitor, C_{14}. This capacitor connects between terminal 4 of the secondary winding of T_3 and the base of Q_3. As you know, the function of C_{14} is to neutralize the effect of base-to-collector capacitance in the transistor. When a large capacitance is placed in parallel, it provides an output-to-input feedback path that allows the stage to oscillate.

Energize the receiver and test its operation. You should be able to tune in some stations satisfactorily. Tuning will be accompanied by squeals and howls. The pitch of the squeals should reduce as you approach the station. The audible oscillations are the difference between the intermediate frequency of the signal and the oscillation frequency. The frequency of the oscillating i-f stage remains constant.

The i-f signal frequency is the difference between the local oscillator signal and the incoming rf signals. This frequency varies as you tune toward and away from the station. Therefore, the pitch of the audible difference frequency changes as you tune the receiver. Knowing these facts gives you a clue to the location of the circuit that is oscillating.

Tune the receiver close to a station so you can definitely hear the oscillation. Next, use a screwdriver to rotate the slot adjustment of the core of the output i-f transformer, T_3.

Listen to the oscillation as you rotate the adjustment. You should be able to detune the transformer enough so that the circuit ceases to oscillate. Detuning the stage reduces the stage gain enough so that the available gain does not exceed the circuit losses. Tune the receiver to other stations to prove to yourself that the circuit is not oscillating. Detuning the transformer reduces the receiver sensitivity, but it operates satisfactorily.

This step illustrates a condition that you will run into in practical servicing. When you attempt to peak up the alignment of the receiver, a stage will break into oscillation. You may not be able to locate the exact cause of the feedback and oscillation, or you may have replaced a transistor or tube with one having higher gain.

In some inexpensive receivers it may be easier to leave a stage slightly mistuned than to try to redesign the stage to eliminate the oscillation. This is particularly true if the receiver has adequate sensitivity with one stage slightly mistuned.

Unsolder and remove the 27 pf capacitor that you connected in parallel with C_{14}. Tune the receiver to the weakest available station. Be sure you are tuned exactly to the station. Readjust the transformer core in T_3 for maximum output. Test the receiver to make sure it is operating properly.

Step 3: To demonstrate the effects of an excessive local oscillator signal.

Tack-solder a 1.2k-ohm resistor on the foil side of the board in parallel with R_{19}, the oscillator supply voltage-dropping resistor. This connection will greatly increase the amplitude of the oscillator signal. Next, tack-solder a short jumper wire in parallel with resistor R_7 in the base circuit of Q_2. Energize the receiver and test the operation, especially on high frequency stations.

The symptoms of this condition are almost the same as when you had the i-f stage oscillating. The large oscillator signal drives the i-f stage so hard that the stage tends to oscillate at its natural frequency. The 100-ohm resistor, R_7, normally increases circuit losses and attenuates the signal that is driving the base.

Unsolder and remove the 1.2k-ohm resistor that you connected in parallel with R_{19}. Unsolder and remove the short bare wire that you connected in parallel with R_7. Test the receiver for proper operation.

Instructions for Statement 67: For this statement you simulate an open filter capacitor in the avc line by removing electrolytic capacitor C_{11} from the circuit board. Turn off the receiver. Carefully unsolder and remove the 10 mfd avc line filter capacitor, C_{11}, from the circuit board. Clean the solder from the mounting holes so the board will be ready when you reinstall the capacitor. Turn the receiver on and test its operation as necessary to answer the statement. Be sure to tune across the entire broadcast band.

Install the 10 mfd capacitor, C_{11}, that you removed from the circuit board. If necessary, remove any excess solder from the capacitor leads so they will fit easily into the mounting holes. Be sure to observe the polarity markings on the capacitor and circuit board. Solder the capacitor leads to the foil on the circuit board. Energize the receiver and test it for proper operation.

Statement No. 67: When I removed the avc line filter capacitor, C_{11}, the receiver,

[✓ *(1)*] *produced motorboating on some stations because of the increased time constant in the avc circuit.*

(2) produced squeals and whistles because the i-f circuit was oscillating.

(3) worked normally except for reduced sensitivity, because there was no avc voltage.

EXPERIMENT 68

Purpose: To show common causes of audio distortion and how to locate them.

Introductory Discussion: Any defect that affects the quality of the reproduced sound from the speaker might be considered audio distortion. The defect may cause a loss of only the low frequencies or only the high frequencies in the received program material.

Loss of lows produces the complaint that the radio sounds "tinny." A loss of highs may be described as causing the set to sound "boomy." The normal audio response curve of an inexpensive radio receiver is quite narrow. The low frequency cut-off point is usually around 100 Hz and the high frequencies fall off rapidly above 6000 or 7000 Hz.

Although this is a very narrow band of audio frequencies by high-fidelity standards, it is most satisfactory for AM radio reception. The attenuation of the high frequencies also attenuates the annoying noise associated with AM reception. The low frequency cut-off helps to prevent hum in a line-operated receiver.

Most receivers have only two audio stages so it is easy to isolate the defective stage. In an earlier experiment, you saw how hum could cause garbled sound when the hum signal entered the signal path in one of the i-f stages. Also, audio distortion can result from a power supply defect. Low supply voltage to the audio stage can upset the stage bias and produce distortion. Such defects are quickly isolated by taking voltage measurements in the audio stages.

When a defective speaker produces audio distortion, the trouble can be isolated by substituting a known good speaker. Mechanical defects are the usual cause of audio distortion from a speaker. The voice coil may become misaligned with the magnet.

Rough handling or a warped speaker frame may cause the voice coil to rub on the magnet. You can usually feel the mechanical contact between the coil and the frame by carefully depressing the speaker cone with your finger. Sometimes the condition can be corrected by evening up the pressure on the speaker mounting screws. Usually the speaker has to be replaced.

Most receivers will distort at full volume on a strong station. A strong local station produces a larger signal than the amplifier can handle. In your receiver, the audio driver stage will clip the peaks of a large audio signal and produce noticeable distortion. Therefore you cannot turn the volume up full on strong stations. The reserve gain of the audio amplifier is useful because it enables you to listen to weak stations. At normal listening levels the receiver has low distortion.

Experimental Procedure: For this experiment you need your operating receiver, hand tools, and the following parts:

1 22k-ohm resistor
1 680-ohm resistor
1 220-ohm resistor
1 .01 mfd capacitor

Step 1: To show how insufficient capacitive coupling causes a loss of low frequencies in the audio signal.

Tune the receiver to a local station and adjust the volume control for normal listening level. Unplug the receiver and do not change the volume control setting. Unsolder and remove the 10 mfd coupling capacitor, C_{16}, from the circuit board. In its place, tack-solder a .01 mfd disc capacitor. Plug in the receiver and listen to the received program.

The most obvious change in operation is reduced volume. When you turn up the volume, speech may sound quite normal. However, if you listen to music, the program material will obviously lack the rich deep tones.

Voltage measurements in the audio stages will not isolate this defect. The condition of reduced capacitance can vary all the way from a completely open capacitor to one having only a small loss of capacitance. When you suspect this condition, the easiest check is to bridge the suspected capacitor with a known good capacitor. Any noticeable improvement in operation indicates a defective capacitor.

Unsolder and remove the .01 mfd capacitor you installed in place of the 10 mfd capacitor for C_{16}. Replace the original capacitor, being sure to observe the correct polarity markings. Solder the capacitor in place and test the receiver for normal operation.

Step 2: To show the effects of a leaky or shorted audio coupling capacitor.

Tack-solder a 680-ohm resistor on the foil side of the board in parallel with the 10 mfd coupling capacitor, C_{16}. This simulates a leaky coupling capacitor. Energize the receiver and test its operation. Measure voltages in the audio stages, Q_4 and Q_5. Compare your readings with those you recorded for normal operation in the voltage chart.

As you would expect, the leaky capacitor allows the positive dc potential present in the detector circuit to be applied to the base of the audio driver, Q_4. This increased positive bias reduces the conduction of Q_4 and lowers the collector voltage. Since the collector of Q_4 is directly coupled to the base of Q_5, the forward bias for Q_5 is reduced.

This in turn reduces the conduction of Q_5 and causes increased collector voltage for Q_5. The circuit distorts the audio signal because the transistors are not operating at the correct point on their transfer curves. You can increase the distortion by replacing the 680-ohm resistor with a direct short.

The voltage readings in the audio stages do not tell you for sure that the capacitor is leaky. Perform this additional test. Tune the receiver to a point between stations. Hold your meter probe on the base of Q_4 and observe the meter reading. Take a dc voltage reading with the volume control at minimum and another reading with the control set to maximum. You should observe a change of at least a volt or more.

Examine the schematic diagram to see why the base voltage changes when the coupling capacitor is leaky or shorted. Normally, no direct current flows through the volume control pot. A leaky or shorted C_{16} completes a dc path from the pot slider to the resistor network in the base of Q_4. DC from the B+ line can now flow through the pot, through C_{16} leakage, and through R_{12} to B-. Changing the setting of the volume control pot changes the drop across its resistance, and therefore changes the voltage reading at the base of Q_4. The results of this test are a pretty good indication that C_{16} is defective.

Unsolder and remove the 680-ohm resistor and/or the short circuit that you bridged across capacitor C_{16}. Operate the receiver and test it for proper operation.

Step 3: To show the effects of increased forward bias on the audio driver stage.

In this step you simulate a condition where a resistor in the base bias network for Q_4 changes resistance. Tack-solder a 22k-ohm resistor from the foil at the base of Q_4 to B-. Energize the receiver and test its operation. Tune to a point between stations and take voltage readings. Record your readings in the chart of Fig. 68-1.

Q4	NORMAL READINGS	R12 WITH 22K IN PARALLEL
BASE TO B-		
EMITTER TO B-		
COLLECTOR TO B-		

Fig. 68-1. Chart for recording voltage readings in Step 3.

Examine the schematic diagram of the receiver and relate the voltage readings to the circuit conditions. Reducing the resistance of R_{12} lowers the normally positive voltage on the base of Q_4. Since this is a PNP transistor, the less positive base voltage means an increase in forward bias.

Your voltage readings reveal that the emitter and the collector are at almost the same potential. This indicates that the transistor is conducting very heavily. These facts should tell you why you have audio distortion. Since the bias very nearly saturates the transistor, it is operating close to one end of its transfer curve and cannot provide linear amplification of the applied audio signal. In fact, the negative portion of the audio signals drives the transistor even further into saturation. Only the positive portions of the audio signals are capable of producing reasonable amplification. The result is a clipped and distorted audio signal.

This defect also increased the forward bias on Q_5 and thereby increased its conduction. The base bias for Q_5 is determined by the voltage drop across R_{15} and R_{16}. The current through these two resistors is determined by the amount of conduction of Q_4. Increased conduction of Q_4, caused by the defect, increased the drop across R_{15} and R_{16} and thereby increased the forward bias for the NPN transistor Q_5.

Step 4: To show the effects of an open capacitor in the emitter circuit of the power output transistor.

Energize the receiver, tune to a local station and adjust volume for normal listening level. Unplug the receiver, being careful not to change the setting of the volume control. Unsolder and remove the 10 mfd electrolytic capacitor, C_{19}, from the emitter circuit of the transistor, Q_5. Energize the receiver and listen to the station with the same setting of the volume control.

The sound will have reduced volume. Now listen to the quality of the program material. It sounds flat even with the volume turned up. The sound seems to lack the low frequencies.

Examine the schematic diagram to see the effect of capacitor C_{19}. This capacitor provides a feedback path from the emitter through R_{15} to the base of Q_5. Since the signals at the base and emitter are in phase (the emitter signal follows the base signal) the feedback is a form of positive feedback. This type of positive feedback increases the gain of the stage and, more important, the feedback increases the input impedance of the stage. The .05 mfd capacitor, C_{17}, is shunted from the base of Q_5 to ground. The effect of this capacitor is to reduce the frequency response of the circuit to high frequencies (especially noise). When C_{19} is removed from the circuit, the middle low frequencies, 200 to 600 Hz, receive much less amplification, causing the "flat" sound of the reproduced program material.

Install the 10 mfd electrolytic capacitor, C_{19}, on the circuit board. Be sure to match the polarity markings on the capacitor with the corresponding markings on the circuit board. Solder the capacitor in place. Test the receiver.

Instructions for Statement 68: For this statement you will change the resistance in the base bias network for the audio output transistor, Q_5, and observe the results. Tack-solder a 220-ohm resistor from the foil at the base of Q_5 to B−. Turn on the receiver and test its operation. Take voltage readings and other tests as necessary to answer the statement.

Unsolder and remove the 220-ohm resistor that you tack-soldered from the base of Q_5 to B−. Test the receiver.

Statement No. 68: When I paralleled R_{15} and R_{16} with a 220-ohm resistor and tested the receiver,

(1) the increased forward bias on Q_5 caused increased gain and badly distorted audio.

(2) the reduced forward bias on Q_5 nearly cut off Q_5, causing clipping of the audio signal and badly distorted audio output.

(3) the reduced forward bias on Q_5 caused loss of audio gain and some distortion.

EXPERIMENT 69

Purpose: To show how the mixer and oscillator functions of the receiver can be combined into a single stage.

Introductory Discussion: Most small inexpensive transistor receivers use a single stage as an oscillator-mixer. The advantages of a separate oscillator stage are improved oscillator stability, a better noise figure, and usually more gain in the converter (mixer) stage. These advantages do not necessarily outweigh the economy of one less transistor. As you know, your receiver has a separate local oscillator stage. In this experiment you rearrange the receiver so transistor Q_2 acts as both the oscillator and the mixer stage.

The simplified schematic diagram in Fig. 69-1 shows the circuit for the combined mixer-oscillator stage. Transistor Q_1 is completely out of the circuit. The emitter circuit for Q_2 is completed through the 5-3 winding of the oscillator transformer, T_1. The B+ dropping resistor, R_{19}, has been paralleled by a resistor to provide enough supply voltage for Q_2. A feedback signal from terminal 4 of the oscillator transformer is coupled through C_7 to the base circuit of Q_2. The signal fed back to the base circuit is of the correct polarity to cause the circuit to oscillate.

The rf signal is fed to the base circuit of Q_2 in the usual manner, and the two signals are mixed in the transistor. Transformer T_2 is tuned to the intermediate frequency to select the difference frequency between the incoming rf and the local oscillator frequency. In this way transistor Q_2 powers the local oscillator and performs the mixing function.

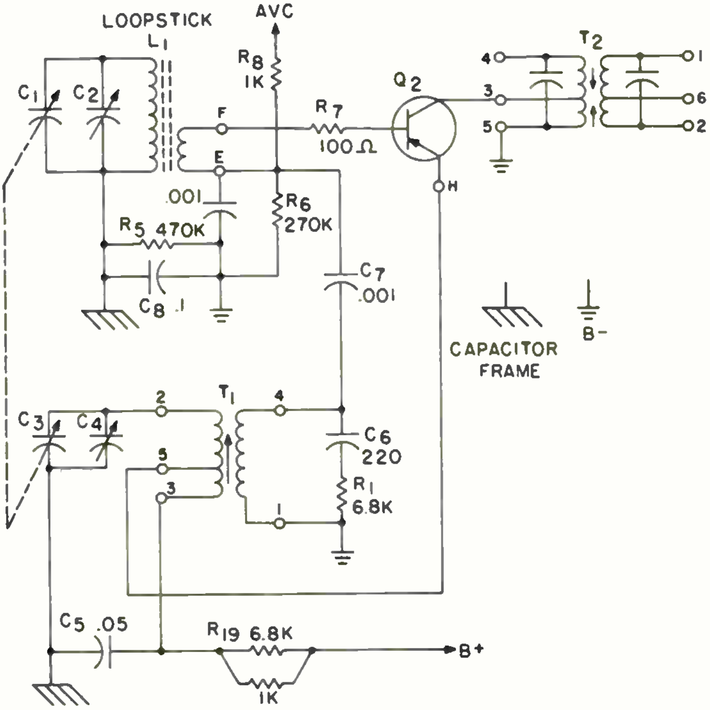


Fig. 69-1. Schematic diagram showing the circuit wired so Q_2 acts as a combined mixer-oscillator stage.

Experimental Procedure: For this experiment you need your operating receiver, voltmeter, hand tools, and the following parts:

1 .001 mfd capacitor
1 1k-ohm resistor

Step 1: To wire your receiver so transistor Q_2 functions as both oscillator and mixer.

Unsolder and remove transistor Q_1 from the circuit board. Unsolder and remove the short jumper wire connected between holes H and I on the circuit board. Unsolder and remove the .005 mfd disc capacitor, C_9, from the circuit board. In its place, tack-solder a .001 mfd disc capacitor. Tack-solder a 1k-ohm resistor in parallel with the 6.8k-ohm resistor, R_{19}, on the foil side of the board. Tack-solder a 1/2" jumper wire from hole H on the circuit board to terminal 5 of T_1 (use the hole where the emitter of Q_1 was connected). Your circuit should now be wired as shown in the schematic in Fig. 69-1.

Energize the receiver and test its operation. You may notice a reduction in sensitivity of the receiver. Also the stations do not come in at the correct place on the dial. The circuit changes have changed the operating characteristics of the oscillator so it does not track the tuned rf circuit of the antenna.

Step 2: To adjust the frequency of the local oscillator so the stations will come in at correct points on the dial.

Tune the receiver to a known frequency station at the low frequency end of the dial. Use a small screwdriver to adjust the core of the oscillator transformer, T_1, to bring the station in at the correct setting of the tuning dial. Next, tune the receiver to a known frequency station near the high frequency end of the dial. Adjust the trimmer capacitor, C_4, on the oscillator section of the tuning capacitor to tune in the station at the correct setting of the tuning dial. Check the reception of the station at the low frequency end of the dial. If necessary, repeat the adjustments until no further improvement is obtained.

Tune the receiver to a station at the high end of the band and adjust the trimmer capacitor, C_2, on the rf section of the tuning capacitor for maximum volume of the received station. Test the receiver and compare its operation now with the operation you experienced when the separate oscillator circuit was in use. You may notice slightly reduced sensitivity but otherwise very little difference. Any difference in the noise figure is probably too small to be noticed.

Step 3: To measure the operating voltage on the combined mixer-oscillator stage.

For this step you measure the voltages in the circuit of transistor Q_2 with it connected as a mixer-oscillator stage. Energize the receiver and tune in a strong local station. Measure the dc voltage between B- and the junction of R_6, C_7, and C_9. Look for a voltage change as you tune across the station.

The positive dc voltage increases when you are tuned exactly on the station, indicating that avc voltage is reducing the forward bias on Q_2 and limiting the gain of the stage. For this hookup, avc is not applied to the base circuit of Q_3.

Next measure the emitter voltage and the B+ voltage. As you can see from the readings, there is very little drop across R_{19} (with the 1k-ohm resistor in parallel). This indicates that the transistor is drawing very little current. Measure the dc voltage between the base and emitter. A typical reading is -.15 volt, indicating that the transistor has only a small forward bias.

Measure the ac voltage at the capacitor terminal of the oscillator section of the tuning capacitor. The probe will detune the oscillator but you should get a reading. Observe the reading as you tune across the band. The output may drop to zero at some points because of the loading of the voltmeter probe.

Leave your circuit wired as it is because you will use it again for the statement of this experiment.

Instructions for Statement 69: For this statement you will change the supply voltage to the mixer-oscillator stage and determine the effect on the operation of the receiver.

Unsolder and remove the 1k-ohm resistor that you tack-soldered in parallel with the 6.8k-ohm resistor, R_{19}. Energize the receiver and test its operation. Take voltage measurements and other tests as necessary to answer the statement.

Turn off the receiver. Unsolder and remove the .001 mfd disc capacitor that you tack-soldered in place of C_9 on the circuit board. Install the .005 mfd capacitor for C_9 on the circuit board. Solder the capacitor in place. Unsolder and remove the 1-1/2" jumper wire that you connected from hole H on the circuit board to terminal 5 of transformer T_1 (terminal 5 connects to the foil at the hole for the emitter lead of Q_1).

Reinstall transistor Q_1. Carefully solder the transistor leads to the foil on the foil side of the circuit board. Install the 3/4" jumper wire from hole H to hole I on the circuit board. Solder the jumper in place. Your receiver is now correctly wired. Energize the receiver and test it for proper operation. Readjust the oscillator frequency and the rf tank circuit as necessary for best operation.

Statement No. 69: When I removed the 1k-ohm resistor that was in parallel with R_{19}, the receiver,

(1) operated normally, with no noticeable change.

(2) operated only on stations at the low end of the broadcast band.

[✓ *(3)*] *failed to operate because the local oscillator dropped out of oscillation.*

EXPERIMENT 70

Purpose: To show receiver alignment problems; and

To show how a receiver can be satisfactorily aligned using only received radio stations.

Introductory Discussion: In the test section of this manual you were shown how to touch up the alignment of your receiver. In an earlier experiment you changed some of the alignment adjustments. Therefore your receiver may not be perfectly aligned at this time. In this experiment you perform various alignment procedures. As a final step you will perform complete alignment to put the set in top operating condition.

Alignment is a regular procedure in repairing radios. After repairing a radio, the least you should do is check to see if the receiver picks up the entire broadcast band and if the stations are received at the indicated points on the dial.

If the receiver seems to lack sufficient sensitivity, you should check the i-f alignment. Making these simple checks will assure customer satisfaction. A touch-up alignment will usually make the receiver operate better then before it developed the defect that you repaired.

Don't expect perfect results when you check the alignment of inexpensive transistor receivers. The tuning dial markings are usually very coarse so you cannot read them accurately. Many receivers will not cover the complete broadcast band from 540 kHz to 1600 kHz. Naturally you should not try to redesign a receiver that does not cover the entire band. Likewise, circuit design or the reception area may produce low sensitivity at some frequencies.

When you touch up the i-f alignment you may find the i-f amplifier oscillates when a certain adjustment is peaked. This condition may have existed since the set was manufactured. The value of your time required to correct this condition could easily exceed the purchase price of the receiver. Again, as a service technician, your repair job should put the receiver back in its original operating condition. If you can improve operation with a touch-up alignment job, you should do it; but you cannot profitably make the alignment perfect on every inexpensive receiver that you repair.

In this experiment you perform alignment using received radio stations. An alignment generator is a real convenience and enables you to do the job quicker. Also, the generator can be used as a troubleshooting tool, but a generator is not absolutely necessary for performing satisfactory alignment on the average radio.

Receiver alignment consists of adjusting the response of three sections of the receiver. These include the i-f amplifier, the local oscillator, and the rf section of the receiver. As you know, the i-f amplifier is a fixed frequency amplifier that provides most of the gain and selectivity of the receiver. In your receiver, the i-f frequency is centered at 455 kHz. The tuned circuits in the i-f amplifier are adjusted to passing a narrow band of frequencies centered around 455 kHz.

The local oscillator is designed to operate above the incoming rf by an amount equal to the i-f amplifier frequency. With this arrangement, the difference between the rf and the local oscillator frequency equals the intermediate frequency.

In your receiver, two adjustments are provided for changing the local oscillator frequency. The core of the oscillator transformer is adjusted to set the frequency of the local oscillator at the low end of the band. A trimmer capacitor in parallel with the local oscillator tuning capacitor is provided to adjust the local oscillator frequency at the high end of the band.

These two adjustments interact to some extent. Adjusting the core of the transformer has a large effect at either the high end or the low end of the band. Adjusting the trimmer capacitor has a small effect at the low end and a large effect at the high end.

At the low end of the band, the tuning capacitor is fully meshed and inserts maximum capacitance in the tuned circuit. In this position a change in the trimmer capacitor represents only a small change in the total capacitance in the circuit.

However, at the high end of the band the tuning capacitor is open, providing minimum capacitance in the tuned circuit. In this position a small change in the trimmer capacitor represents a large percentage change in the total capacitance in the circuit.

Edge capacitance increases the tuning capacitance at the extreme unmeshed position of the tuning capacitor. As the tuning capacitor rotor is rotated counterclockwise, the rotor plates unmesh from the stator plates, causing the circuit capacitance to decrease. However, when the stator plates approach the full unmeshed position, the edges of the rotor plates approach the opposite edges of the stator plates.

This proximity of the plate edges causes the circuit capacitance to increase for the last few degrees of rotation as you reach the high frequency end of the dial. As a result, you may receive the high-frequency station at two points near the high frequency end of the dial. For example, a station at 1600 kHz may be received with the plates fully unmeshed. Then as you rotate the tuning capacitor a couple of degrees clockwise, you will again receive the same station.

Edge capacitance causes the oscillator to produce the correct local oscillator frequency at both positions of the tuning dial. This condition is normal. Simply disregard the last few degrees of rotation near the fully unmeshed position of the tuning capacitor.

The rf section of the receiver consists of only the tuned tank circuit of the antenna. This is the usual arrangement for receivers. Very few broadcast receivers have an rf stage. A trimmer capacitor on the rf section of the tuning capacitor is provided for adjusting the frequency of the rf tank circuit. The trimmer has the greatest effect at the high end of the band and is usually adjusted for maximum response to a frequency near the high end of the band.

Experimental Procedure: For this experiment you need the operating receiver and your hand tools.

Step 1: To demonstrate improper tracking due to a misadjusted trimmer capacitor on the local oscillator circuit.

For this step you misadjust the trimmer capacitor on the local oscillator section of the tuning capacitor and observe the effect.

Tune the receiver to a local station near the upper end of the band. Try to select a station between 1400 and 1200 kHz for best results.

Suppose you select a station at 1240 kHz. Since your tuning dial is only roughly marked, it reads only the approximate frequency of the station you are tuned to. Now tighten the oscillator trimmer capacitor a small fraction of a turn. Readjust the tuning capacitor toward the high end of the dial to again receive the station at a frequency of 1240 kHz. Repeat the above process until you have the trimmer capacitor adjustment nearly tight, and you are receiving the 1240 kHz station at or near the full open position of the tuning capacitor.

What you have done is increase the capacitance by tightening the trimmer capacitor and decrease the capacitance by opening (unmeshing the plates of) the tuning capacitor. You are receiving a station of 1240 kHz, and the tuning dial is indicating nearly 1600 kHz. The loudness of the station probably decreased considerably as you changed the adjustment. The reason for the reduced sensitivity is the loss of rf tracking. That is, the rf section of the tuning capacitor is adjusted for receiving stations close to 1600 kHz when the plates of the tuning capacitor are nearly open.

The fact that you can still receive the 1240 kHz station indicates that the rf section of your receiver is rather broadly tuned. Receiver selectivity is accomplished by the i-f amplifier rejecting those signals that do not fall in the i-f bandpass. Tune your receiver to other stations toward the low end of the band. You will find that all the stations you receive come in at points higher on the dial than they should.

Readjust the local oscillator trimmer capacitor so that the stations track the dial markings. Since you are adjusting only the trimmer, it is easiest to do it on the highest frequency station that you can receive. Simply set the dial to the correct point where you should receive the highest frequency station. Then adjust the oscillator trimmer until you hear that station.

Step 2: To demonstrate improper tracking due to a misadjusted oscillator transformer core.

For this step you again change the frequency of the local oscillator, but you do it by changing the inductance of the tuned circuit. As you know, the oscillator transformer has an adjustable core. Changing the setting of the core changes the inductance of the transformer, and thereby changes the frequency of the local oscillator. This, in turn, will change the point on the dial where you receive a given station.

Tune the receiver to a station near the low end of the broadcast band. Locate the oscillator transformer, T_1, on your circuit board. Use a screwdriver to adjust the slotted core in the top of the transformer. Tune the core a fraction of a turn counterclockwise.

Adjust the tuning dial so that you again receive the same station. Notice that you have to tune to a lower frequency to receive the station. Turning the adjustment counterclockwise in T_1 decreased the inductance and increased the frequency of the local oscillator. To correct for this you had to insert more capacitance into the circuit by moving the tuning dial toward the lower end. Readjust the core of T_1 so the station comes in at the proper place on the dial.

Next, tune to a station near the high end of the broadcast band. Adjust the core of the oscillator transformer slightly clockwise. Adjust the tuning capacitor to again receive the same station. Notice that you have to tune toward the high frequency end of the dial to receive the station. Readjust the core, T_1, so that the station comes in at the correct place on the dial.

In Step 1 of this experiment, you found that adjusting the oscillator-trimmer capacitor had the greatest effect at the high end of the band. This is because a change in the trimmer capacitance represents a larger percentage change in the total capacitance at the high frequency end of the band.

In this step you found that a change in the inductance of the oscillator transformer had about the same effect at either the high or the low end of the band. This is what you would expect because the inductance is not varied when you tune across the band. You will take advantage of these facts when you perform receiver alignment.

Step 3: To show the effects of aligning the i-f amplifier to the wrong frequency.

In this step, you align the i-f amplifier to a frequency lower than 455 kHz, and observe the effect on the operation of your receiver.

Tune your receiver to a local station that you can readily identify. Note the exact position of your tuning dial. Since the dial is only coarsely graduated with the approximate station frequency, you'll have to mark the dial. Use a crayon or a piece of tape to temporarily mark the exact position of the dial. For example, tune the receiver exactly to the selected station and place a small piece of tape on the tuning dial so that the edge of the tape lines up with one edge of the red line behind the dial. Leave the tape in place for now.

Use your alignment tool to change the adjustments in the i-f amplifier transformer, T_2. Turn the top slug of T_2 two full turns clockwise. Next reach through the hole in the circuit board at the center of T_2 and adjust the bottom slug of T_2 two full turns clockwise. Now use a screwdriver to adjust the slug of the transformer T_3 about one-half turn clockwise. These adjustment changes have tuned the i-f amplifier to a lower frequency of approximately 400 kHz. Without a signal generator, you have no way of knowing the exact frequency. Also, the adjustments are not peaked to the new intermediate frequency.

To peak the i-f adjustments, tune the receiver to a weak station and readjust the i-f transformers. Move each slug as necessary to increase the volume of the station that you are tuned to. Go over the adjustments two or three times in order to get the greatest possible response.

Tune your receiver to the station that you marked with the tape on the dial. Definitely identify the station and set the tuning dial until you are tuned exactly on the station.

Now observe the mark that you put on the dial in relation to the red line. You will find that you had to move the dial about 1/16" clockwise to receive the station with the i-f amplifier tuned to a lower frequency.

To understand why the dial position shifted for receiving the selected station, think through the operation of your receiver. Suppose the selected station transmitted at a frequency of 1000 kHz. When your i-f was tuned to 455 kHz, you had to tune your receiver until the local oscillator produced a frequency of 1455 kHz. The difference between the incoming rf signal of 1000 kHz and the local oscillator frequency of 1455 kHz was 455 kHz, which is also the frequency that your i-f amplifier was tuned to. This setting enabled you to receive the station.

Let's see just what happened when you realigned your i-f amplifier to 400 kHz. To receive the 1000 kHz station you had to produce a local oscillator signal that was 400 kHz above the incoming rf signal. Or you need a local oscillator signal of 1400 kHz.

To get the local oscillator frequency down to 1400 kHz, it was necessary to adjust the tuning dial to a point where it would increase the capacitance in the oscillator circuit. The increased capacitance tuned the oscillator to a lower frequency of 1400 kHz. Now the difference is 400 kHz, and you receive the selected station but at a different point on the dial.

Steps 1, 2, and 3 of this experiment should help you to understand alignment procedures. As you know, the i-f amplifier processes only those signals having the frequency to which the amplifier is tuned. Therefore, to receive a certain station, you must generate a local oscillator frequency that is above the incoming rf signal by an amount equal to the i-f. Also, the tuning dial should be calibrated to indicate the received station frequency when the dial is in the correct position to produce the required local oscillator frequency. Likewise, the rf section should be tuned to the indicated frequency.

Step 4: To show how to perform touch-up alignment on your receiver using only received radio stations.

A signal generator is a real convenience for quick, accurate alignment of a radio receiver. If you are used to using a signal generator for alignment, you will probably find this step slow and clumsy. You should perform the step anyway. What you learn will be useful for touch-up alignment of receivers when you do not want to go to the trouble of setting up a signal generator.

At the present time, your receiver has the i-f amplifier aligned to approximately 400 kHz. First we will retune it to approximately 455 kHz. Use your alignment tool to adjust slugs in the transformer, T_2. Tune the top slug two turns counterclockwise. Reach through the hole in the circuit board and turn the bottom slug of T_2 two turns counterclockwise.

Use a screwdriver to turn the adjustment on transformer T_3 one-half turn counterclockwise. Set your tuning dial to the position you marked with the tape so you receive the selected station. The station may come in very weak or you may have to tune slightly off the correct point to hear it at all.

Readjust the top and bottom slug in T_2, and the screwdriver adjustment on T_3 to get maximum volume. Recheck the setting of the tuning dial. If you had to offset is slightly before, you should now be able to set it exactly on and still be able to hear the station. Readjust the preceding three adjustments for maximum volume.

These adjustments should have returned your i-f to 455 kHz, but you may be able to improve the alignment. Tune your receiver to the weakest available station. If all available stations are strong, connect a clip lead from the trimmer capacitor terminal on the rf section of the tuning capacitor to the ground lug on the capacitor frame.

The clip lead shorts out the rf section of the antenna and greatly attenuates the received signals. Again, tune the receiver to a weak station. Make sure you are tuned to the exact center of the received signal. Now readjust the slugs of T_2 and T_3. Tune each slug for the maximum received signal. Your i-f amplifier is now peaked at approximately 455 kHz. Remove the clip lead you used to short out the antenna.

Tune your receiver to the lowest frequency station available in your area. Identify the frequency of the station and check the tuning dial to see if the station comes in at the correct point on the dial.

Since the dial is only roughly graduated, you have to estimate the correct position. If necessary, set the tuning dial to the correct position and adjust the slug in the local oscillator transformer, T_1, to bring in the station. Clockwise rotation of the slug increases the inductance and lowers oscillator frequency.

Next, tune the receiver to the highest frequency station available in your area. Again check the tuning dial reading to see if the station is received at the correct position on the dial. If not, set the dial to the correct point and adjust the trimmer capacitor on the oscillator section of the tuning capacitor to bring in the station.

Recheck reception at the low end of the band. If you made large changes in either adjustment, it may be necessary to repeat both adjustments until no further improvement is possible.

Peak up the adjustment on the rf section. Tune the receiver to a weak station at the high frequency end of the dial. Adjust the trimmer capacitor on the rf section of the tuning capacitor for maximum volume.

This procedure may not produce perfect alignment, but it is satisfactory for all practical purposes. For example, your i-f amplifier is probably not aligned to exactly 455 kHz. Your receiver may not tune to the extremes at both ends of the band. The stations may not come in at exactly the correct point on the tuning dial, and the rf section may not track across the entire band. But you receive all available stations with adequate volume.

Step 5: To perform complete alignment procedures using only the received radio stations.

In this step we assume that your receiver is completely misaligned so that you are unable to receive stations at all. This could happen if you failed to identify adjustments before you moved them, or you may have had a defect in the receiver and thought the problem was alignment. The procedure we give here will enable you to realign the receiver using only received radio station signals. Some steps in this procedure will involve trial and error before you get all sections of the receiver tracking properly. The following adjustments steps, (a) through (e), are followed by a discussion of what to do if you are unable to get satisfactory results from some steps.

(a) Preset all adjustments. Do not force any adjustment beyond its limit, or point where the adjustment moves easily. The preset positions we give here are a starting point from which you will perform the alignment. Tighten the trimmer capacitors on the tuning capacitor. Then turn each trimmer screw one-half turn counterclockwise. Adjust the slug of the oscillator transformer, T_1, to its mid-position. The full adjustment range of the slug is about two turns, so tighten the slug and then turn it counterclockwise one full turn. Do the same for the i-f output transformer T_3.

Preset the slugs in the i-f transformer, T_2. Start by moving the slugs to the ends of the coils so that there is maximum separation between the slugs. Next, adjust the top slug about four full turns clockwise so the top of the top slug is about 3/8″ from the top of the can. In the same way, adjust the bottom slug four full turns into the coil, so the bottom slug is 3/8″ up from the circuit board.

All alignment adjustments are now preset to an approximate position, so you should be able to receive at least one station, although it may come in weak. Move the tuning knob slowly across the band until you pick up a station. Disregard the frequency of the station or where it comes in on the dial.

(b) Align the i-f amplifier for maximum signal on a received station. Adjust the top and bottom slugs in T_2 and the single slug in T_3 for maximum signal. If the station becomes too strong, tune to a weaker station. Most accurate adjustments are made on the weakest signal that you can hear. Readjust all three i-f adjustments until no further improvement is possible. The i-f amplifier is now aligned, although it may not be aligned to exactly 455 kHz.

(c) Adjust the oscillator frequency at the low end of the broadcast band. Identify the lowest frequency station that you can receive. Set the tuning dial to the correct point where the station should be received. Adjust the slug in the oscillator transformer, T_1, to bring in the station.

(d) Adjust the oscillator frequency at the high end of the broadcast band. Identify the highest frequency station you can receive. Set the tuning dial to the correct point where that station should be received. Adjust the trimmer capacitor on the oscillator section of the tuning capacitor to bring in the station. Repeat steps (c) and (d) until no further improvement is obtained.

(e) Adjust the trimmer capacitor on the rf section of the tuning capacitor. Tune the receiver to the highest frequency station you receive. Be sure you are tuned exactly to the station. (Tune for maximum volume.) If you have a choice of several stations near the high end of the band, select the weakest station. Adjust the trimmer capacitor on the rf section of the tuning capacitor for maximum received signal.

If you were able to complete each of the five steps listed above, your receiver is probably satisfactorily aligned. Check the receiver operation to see if all available stations are received at the correct points on the dial.

Since the dial is only roughly calibrated, you have to estimate the exact frequency readings. Unsatisfactory alignment may show up as inability to receive stations at the high end or the low end of the band, low sensitivity, stations received at the wrong points on the dial, or i-f oscillation.

Try repeating steps (b) through (e). Examine the position of each adjustment to see if it is very far from the preset position. You should be able to hear the response fall off each side of the correct adjustment point when making each adjustment.

In step (d), if you turn the trimmer capacitor much more than one full turn counterclockwise, the adjustment screw becomes quite loose and has little effect. To correct this, readjust the slug in T_1 a fraction of a turn counterclockwise. This reduces the inductance and increases the oscillator frequency.

The trimmer adjustment point will be reached with the screw closer to the tightened position. Changing the oscillator slug will move the lowest frequency station down on the tuning dial. You may have to compromise to get a satisfactory adjustment in both steps (c) and (d).

Low sensitivity can be caused by the i-f amplifier being improperly aligned. Peak each adjustment in step (b) on the weakest available station signal. Be sure that the response falls off either side of the final adjustment point of each slug. Be sure that the slugs are somewhere close to the preset positions given in step (a).

If you are unable to receive the highest frequency stations or the lowest frequency stations, your i-f may be aligned to a frequency far from 455 kHz. As a result, you may be unable to adjust the oscillator adjustments far enough to receive some stations. Try changing the alignment frequency of the i-f amplifier. To lower the frequency, turn each slug in transformer T_2 one-quarter turn clockwise (move both slugs toward the center of the coil). Turn the slug on T_3 one-eighth turn clockwise. Tune to a weak station and perform step (b). This will align the i-f at a lower frequency. Now repeat steps (c),(d), and (e).

You can raise the i-f amplifier alignment to a higher frequency by moving the i-f transformer slugs counterclockwise. Adjust each slug in T_2 one-fourth turn counterclockwise. Move the slug in T_3 about one-eighth turn counterclockwise. Tune to a weak station and peak up the i-f adjustment as outlined in step (b). This will align the i-f amplifier to a higher frequency. Again perform steps (c), (d), and (e). By repeating these steps you should be able to find an i-f amplifier frequency that will enable your receiver to track satisfactorily.

Instructions for Statement 70: For this statement you will change the frequency of the local oscillator by paralleling the oscillator section of the tuning capacitor with a 27 pf capacitor and observing the results.

Tack-solder a 27 pf disc capacitor from the terminal on the oscillator section of the tuning capacitor to the solder lug on the frame of the tuning capacitor. Energize the receiver and test its operation as necessary to answer the statement.

Unsolder and remove the 27 pf capacitor that you tack-soldered from the terminal of the oscillator section of the tuning capacitor to the ground lug on the frame of the tuning capacitor. Test the receiver for proper operation.

Statement No. 70: When I placed a 27 pf capacitor in parallel with the oscillator section of the tuning capacitor,

(1) all stations that I could receive were received at a lower frequency setting of the tuning capacitor.

[✓ *(2)*] *all stations that I could receive were received at a higher frequency setting of the tuning capacitor.*

(3) the receiver failed to operate because the local oscillator failed to oscillate.

Installing the Receiver In the Cabinet

Now that you have completed the experiments, you will want to install the receiver in its cabinet for normal use. In the final experiment you performed alignment. Your receiver should now be in tip-top operating condition. Examine the circuit board and other parts carefully.

Look for poorly soldered connections or bits of wire that could short out the circuits. See that the wiring, especially around the loopstick antenna and on the volume control potentiometer, is dressed close to the panel so that the wires will clear the cabinet. When you are satisfied with the condition of the receiver, perform the following steps to install it in the cabinet.

Remove the power cord from both the receiver and from the ac outlet.

Insert the interlock end of the power cord through the rectangular cutout marked "Interlock" . . . . ( )

Slip the power cord clamp on the interlock connection, as shown in Fig. 23. . ( )

Pull the cord through the rectangular cutout until the interlocking portion of the cord extends through the rectangular cutout, as at "1" in Fig. 24. The power cord clamp is now positioned against the inside of the cabinet at the cutout . . . .( )

With the cabinet right-side up, position the receiver so the circuit board rests in the guide strips on either side of the inside of the cabinet . . . . ( )

Slowly slide the receiver into the cabinet. Position the interlock connector so the interlock prongs on the circuit board fit into the female connector on the power cord . . . . ( )

To make sure that the interlock is correctly seated, plug in the receiver and turn it on. If it operates, the interlock is

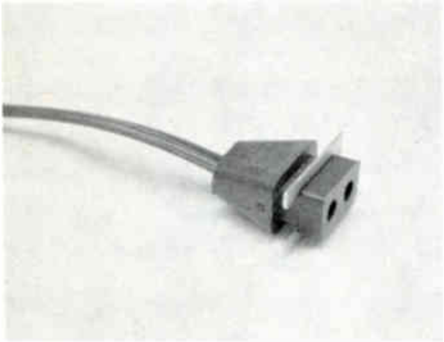


Fig. 23. Placement of the cord clamp on the interlock.

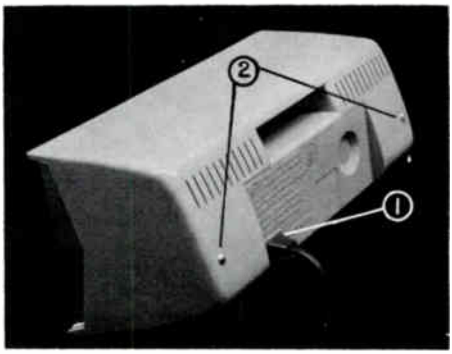


Fig. 24. Mounting the receiver in its cabinet for normal use.

properly connected. If it does not operate, pull the receiver forward and reseat the interlock connector . . . . ( )

Place the two 4-1/4" screws through the two holes in the rear of the cabinet as shown at "2" in Fig. 24. Tighten the screws evenly . . . . ( )

Your receiver is now completely assembled and installed in its cabinet ready for normal use.

NOTES

WHY DO YOU WANT TO SUCCEED?

There are several answers to this question. You may want to succeed for the very human reason that you want more money with which to enjoy life, or you may have a family for whom you want to provide those comforts they deserve – a home, a new car, good clothes, life insurance, and financial security.

Your ambition to succeed may be promoted by the desire to bring happiness to an aged father, mother, or relative whose chief hope in life is to see that you enjoy prosperity and prestige, to see you on the pinnacle of success.

Pause for just a minute and think – what is your reason for wanting success? With this reason in mind, resolve firmly that you will never allow your ambition to weaken. Resolve that you will never swerve from the direct path of your goal. Make this resolution now and keep it, so the years to come will be happier and more prosperous for you.

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ACHIEVEMENT THROUGH ELECTRONICS

TRAINING KIT MANUAL

7YY

NATIONAL RADIO INSTITUTE • WASHINGTON, D. C.

PRACTICAL DEMONSTRATIONS OF RADIO-TV FUNDAMENTALS 7YY

INSTRUCTIONS FOR EXPERIMENTS 61 TO 70

In this kit you build a complete 5-tube ac-dc receiver and conduct experiments on it. This is an excellent receiver that you can use in your home or in your shop.

INDEX OF SECTIONS

NATIONAL RADIO INSTITUTE, WASHINGTON, D.C. 20016

CEC5C176 1976 EDITION Litho in U.S.A.

Instructions for Performing Experiments 61 to 70

The experiments that you have carried out so far have shown how certain stages in a receiver operate, but you have not yet worked on a complete receiver.

Before you carry out any of the experiments in this manual, you will assemble a complete 5-tube ac-dc radio receiver. This is the type of table model radio most commonly used today, and ac-dc TV sets are also quite common.

You will then learn the correct troubleshooting procedures for locating the cause of a dead receiver, a receiver with hum, and af and i-f oscillations. You will show how important i-f alignment is for tracking and sensitivity of superheterodyne receivers. You learn three different methods of troubleshooting radio receivers; the voltage measurement, resistance measurement, and circuit disturbance methods. You see where each of these methods should be used and learn the limitations of each.

Building a complete receiver and then making standard servicing checks on it will give you valuable practical training. When you finish the experiments, you will have an excellent receiver complete with modern cabinet that you can use in your home, as a shop set, or as a set to lend out to customers while their sets are in your shop.

You will wire the set in steps. When you finish each step, you should check your work carefully. After you have completed the receiver, carry out each test procedure carefully and completely. If you fail to get the correct results, recheck your work and correct the trouble before you go on to the next step. If you cannot locate the trouble, write to NRI on a regular Experiment Consultation Blank. When you write for help, be sure to give complete details, because the only information we will have is what you send in your letter.

Even if the set is completely dead, take the voltage and resistance measurements indicated on pages 22 and 23, and let us know the results. This information will help us locate your trouble.

CONTENTS OF THIS KIT

In this kit you will receive two new tubes, a 50C5 power output tube, and a 35W4 rectifier tube. You will also receive a loudspeaker, a two gang tuning capacitor, a dual section electrolytic capacitor, and various resistors and capacitors.

IMPORTANT: The i-f transformers sent in this kit have been pretuned at the factory. Do not turn the adjustments on these i-f transformers until you are told to do so. If you do, you may get them so badly out of adjustment that you will not be able to align the set without a signal generator.

The parts included in this kit are illustrated in Fig. 1, and are listed in the caption below it. Check the parts you received against this list to be sure you have all of them.

If any part of this kit is obviously defective or has been damaged in shipment, return it to NRI immediately as directed on the packing slip included in this kit.

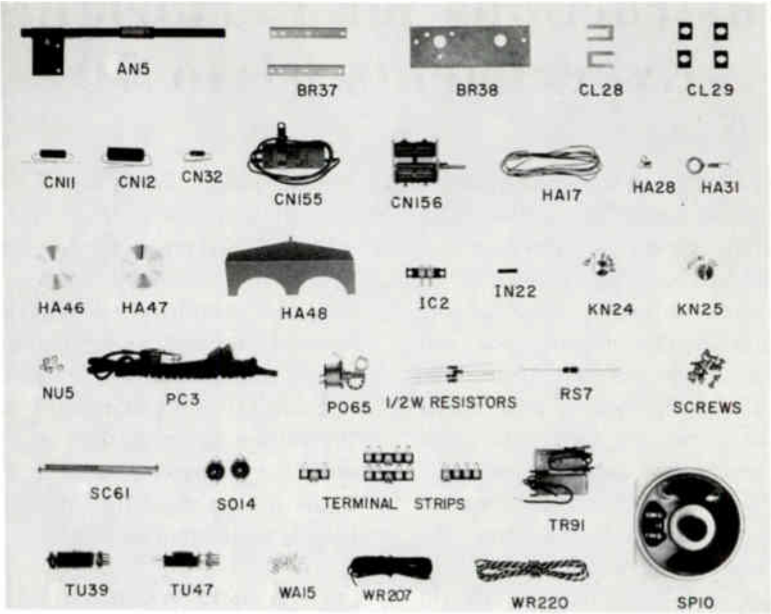

Fig. 1. The parts you receive in this kit are shown above and listed below.

Quan.	Part No.	Description	Price Each
1	AN5	Loopstick antenna	1.06
1	AT3	Alignment tool*	.40
1	CB15	Plastic radio cabinet*	3.65
1	CH50	Chassis*	2.60
1	HA8	3′ length solder	.10
1	IC2	Chassis interlock connector	.25
1	IN22	5/8″ length spaghetti	.10
1	KN24	Tuning knob	.48
1	KN25	Volume control knob	.48
6	NU5	4-40 hex nuts	12/.15
1	PA17	Front panel*	1.70
1	PC3	Interlock power cord	.58
1	PO65	500k-ohm pot. w/switch	.95
2	SO14	7-pin miniature sockets	.15
1	SP10	4″ loudspeaker w/mtg. slot	1.59
2	TR91	455 kHz i-f transformers	1.30
1	TU39	50C5 tube	1.10
1	TU47	35W4 tube	.83
24	WA15	No. 6 split-ring washers	12/.15
1	WR207	6′ length hookup wire	**
1	WR220	36″ length black and white twisted wire	.35

*Not shown in photo.

** Additional wire available in 12′ lengths only, each color .25.

CAPACITORS

1	CN50	25 pf	.15
1	CN32	47 pf	.15
1	CN11	0.01 µf	.18
1	CN12	0.1 µf	.18
1	CN155	50-30 µf, 150-volt, elect.	1.24
1	CN156	Two-gang tuning	1.57

HARDWARE

2	BR37	Chassis support brackets	.55
1	BR38	Volume control bracket	.70
2	CL28	Power cord clamps	.15
4	CL29	Speaker mounting clips	12/.15
3	HA28	1/4" spacers to pass No. 6 screws	.05
1	HA31	Pot. ground lug	12/.25
1	HA46	Plain round dial plate	.21
1	HA47	Round dial plate w/red line	.35
1	HA48	Gray edge molding	.40
1	ST5	2-lug terminal strip	.04
2	ST21	4-lug terminal strips	.10
1	ST28	4-lug terminal strip	.09

RESISTORS

(All resistors are 10%, 1/2-watt unless otherwise specified)

2	RE47	150-ohm	.15
1	RE44	2.2-megohm	.15
1	RE42	10-megohm	.15
1	RS7	1 k-ohm, 1-watt	.18

SCREWS

4	SC6	4-40 X 1/4"	12/.15
2	SC11	6-32 X 1/4" spade bolts	12/.15
4	SC13	6-32 X 3/8"	12/.15
6	SC15	No. 6 X 1/4"	12/.15
2	SC61	8-32 X 4-1/4"	.12

Assembling Your Experimental Receiver

In all the assembly instructions, read the entire sentence or paragraph of each step before you proceed with the actual construction. Position each part and lead according to the description and illustrations. Be sure and cut the leads of all parts to the proper length for neat assembly. You will not be using any of these parts in later kits. Solder carefully. Above all, take your time. The few extra minutes it takes for careful construction may save you hours of checking to find a mistake. As you complete a step, put a check in the space provided.

MOUNTING THE PARTS

Before you do any wiring, you will mount most of the parts on the chassis and front panel. Gather the following parts from those you had left over from your other kits and from those you received in this kit.

1	Front panel
1	Round dial plate with red line
1	Plain round dial plate
1	Gray edge molding
2	Chassis support brackets
2	6-32 X 1/4" spade bolts
4	No. 6 X 1/4" self tapping screws
1	Chassis
2	I-F transformers
5	7-pin miniature tube sockets
1	Oscillator coil
2	4-lug terminal strips
1	3-lug terminal strip with ground lug
1	2-lug terminal strip
1	Audio output transformer
1	Dual 50/30 electrolytic capacitor
12	4-40 X 1/4" screws
12	4-40 hex nuts
5	6-32 X 1/4" screws
4	6-32 X 3/8" screws
12	6-32 hex nuts
22	No. 6 lockwashers
1	Male chassis interlock connector
1	Volume control bracket
1	Tuning capacitor
1	500k-ohm potentiometer with switch, lockwasher and mounting nut
1	Potentiometer ground lug
1	Ferrite antenna rod
1	Antenna coil
1	Fiber antenna mounting bracket
3	1/4" spacers

Decorative Trim. Refer to Figs. 2(A) and 2(B) as you mount the decorative trim on the front panel.

Position the dial plate with the red line so that the red line is pointing straight up. Put the dial plate in the upper recess of the panel after bending the three tabs so they pass through slots 1, 2, and 3 of the panel as shown in Fig. 2(A). The red line should be between slots 1 and 2. . . (✓)

Put the plain round dial plate in the lower recess after bending the three tabs so they pass through slots 4, 5, and 6. (✓)

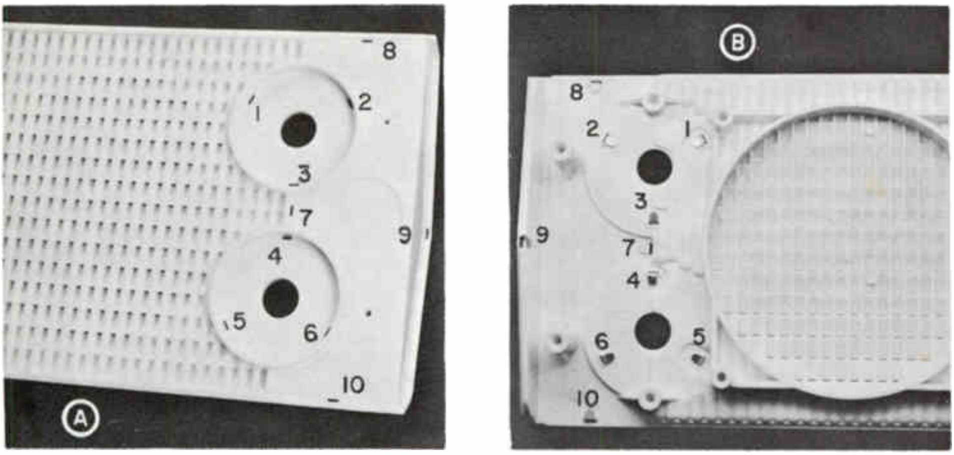

Fig. 2. (A) Mounting slots for panel trim, (B) bending mounting tabs of panel trim.

Mount the gray edge molding so the four mounting tabs pass through slots 7, 8, 9, and 10. Slot 9 is on the rear edge of the panel. . . . . (✓)

With the three trim pieces pressed firmly against the front panel, bend the ten mounting tabs as shown in Fig. 2(B). (✓)

Chassis Support Brackets. The next step will be to prepare the chassis support brackets and fasten them to the front panel. This step is shown in Figs. 3 and 4.

Fasten one of the 6-32 spade bolts in hole B of one of the chassis support brackets as shown in Fig. 3. Position the "spade" part parallel to the short dimension of the bracket, and secure with a No. 6 lockwasher and a 6-32 hex nut. . . . ( )

In a similar manner, fasten the other 6-32 spade bolt in hole B of the other chassis support bracket. . . . . ( )

Place the front panel face down on a cloth in front of you. Position the two large holes in the panel to your left, as shown in Fig. 4. . . . . ( )

Place one of the two chassis support brackets over the two posts on the left of the panel: Position the bracket so that holes A and D are over the holes in the ends of the posts. The "spade" part of the spade lug should be nearest you and pointing straight up. . . . . ( )

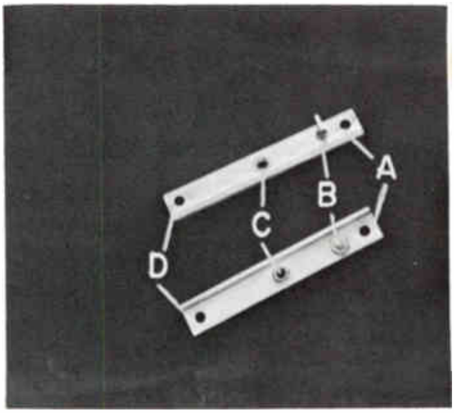

Fig. 3. Chassis support brackets.

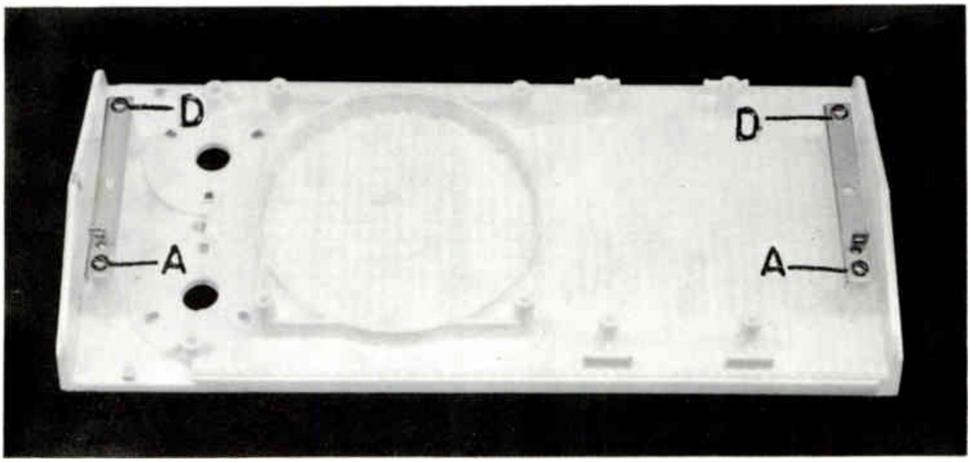

Fig. 4. Rear of front panel.

Fasten the bracket to the front panel with two No. 6 X 1/4" self-tapping screws. It is important that you tighten these screws very slowly and that you do not overtighten them. The plastic posts, while strong, may crack if too much force is used in tightening these screws. . . . ( )

In a similar manner, fasten the other chassis support bracket to the two posts on the right end of the front panel. Figure 4 shows the chassis mounting brackets in place. . . . . ( )

Mounting Parts On The Chassis. Figure 5 identifies the various holes in the chassis as viewed from the bottom. You can mark the chassis with a marking crayon if you wish. Refer to Figs. 5, 6, and 7 as you mount the parts.

Position the chassis in front of you as shown in Fig. 5. . . . . ( )

Place a 7-pin socket in hole B. Pass a 4-40 X 1/4" screw through hole B1 from the top of the chassis and fasten with a

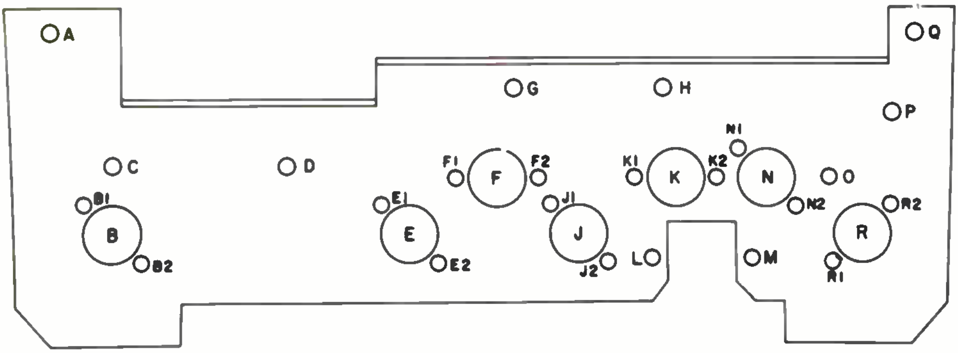

Fig. 5. Bottom view of receiver chassis with holes identified.

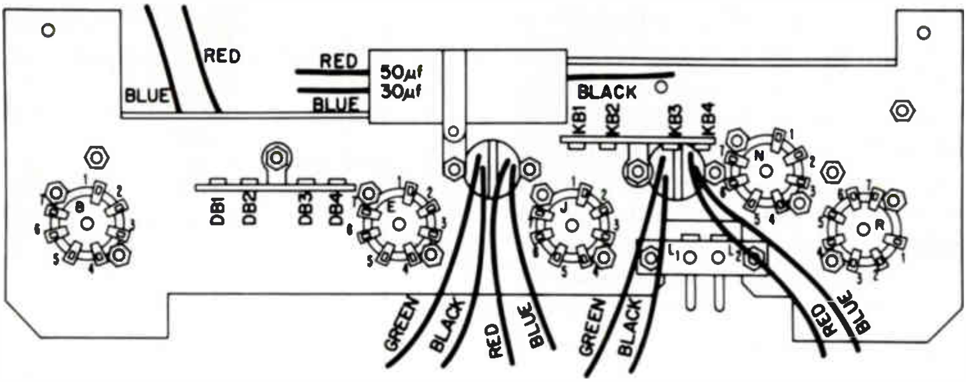

Fig. 6. Parts mounting on bottom of chassis.

No. 6 lockwasher and a 4-40 hex nut. Secure the socket with another 4-40 X 1/4" screw, lockwasher, and nut in hole B2. Be sure the socket is positioned with the space between pins 1 and 7 as shown in Fig. 6. This socket will be referred to as "socket B." . . . . ( )

In a similar manner, mount sockets in holes E, J, N, and R. Position these sockets as shown in Fig. 6. . . . . ( )

Using two 6-32 X 1/4" screws, two No. 6 lockwashers, and two 6-32 hex nuts, mount the male interlock connector in the space between holes L and M. . ( )

Mount the oscillator coil on top of the chassis with two 6-32 X 1/4" screws, two No. 6 lockwashers, and two 6-32 hex nuts in holes O and P. Position the lugs with the red, black, green, and orange dots as shown in Fig. 7. . . . . ( )

Mount the output transformer on top of the chassis with a 6-32 X 1/4" screw, No. 6 lockwasher, and 6-32 hex nut in hole C. Position the transformer so the red and blue leads are shown in Figs. 6 and 7. . . . . ( )

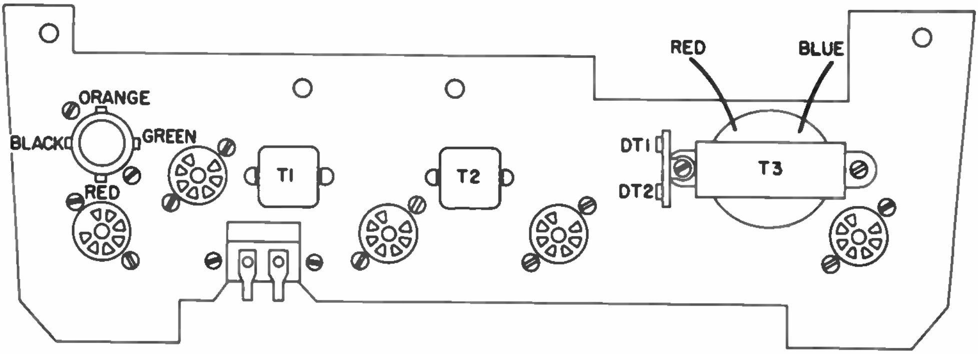

Fig. 7. Parts mounting on top of chassis.

Pass a 6-32 X 3/8" screw through the mounting foot of the 2-lug terminal strip, then through the remaining mounting hole of the output transformer from the top of the chassis over hole D. Place a 4-lug terminal strip on the projecting end of this screw and fasten with a No. 6 lockwasher and a 6-32 hex nut. Position the lugs of the two terminal strips as shown in Figs. 6 and 7 and tighten the nut securely. . . . . ( )

Next, you are to mount the two i-f transformers on top of the chassis. Pass the leads of one of the i-f transformers through hole K from the top of the chassis. Turn the transformer so the red and blue leads will be in the position shown in Fig. 6. Run the spade bolts on the shield can through holes K1 and K2. . . . . ( )

Place a No. 6 lockwasher and a 6-32 hex nut on the spade bolt projecting from hole K2 and tighten just enough to securely hold the transformer. Too much force may pull the spade bolts from the can. . . . . ( )

Position the other 4-lug terminal strip over the spade lug projecting from hole K1 as shown in Fig. 6 and secure with a No. 6 lockwasher and 6-32 hex nut. . ( )

Mount the other i-f transformer in hole F. Position the leads as shown in Fig. 6 and secure with one No. 6 lockwasher and one 6-32 hex nut at F2. . . . . ( )

Mount the dual electrolytic capacitor on the remaining spade lug at F1 with a No. 6 lockwasher and a 6-32 hex nut. Position the red, blue, and black leads as shown in Fig. 6. . . . . ( )

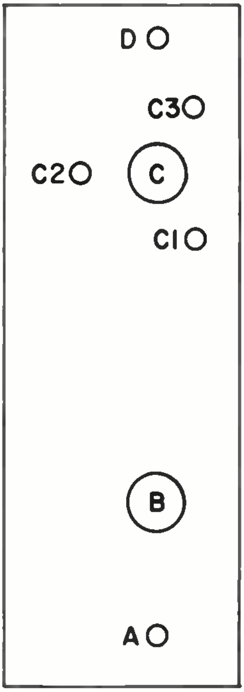

Fig. 8. Rear view of volume control bracket.

Mounting Parts On The Volume Control Bracket. Figure 8 shows the rear of the volume control bracket and identifies the holes.

Place a lockwasher and then the potentiometer ground lug over the shaft of the 500k-ohm potentiometer with the bent lug pointed to the rear of the control. ( )

Push the shaft of the potentiometer through hole B of the volume control bracket. Position the lugs as shown in Fig. 9 and fasten with the potentiometer mounting nut. . . . . ( )

Place three 6-32 X 3/8" screws through holes C1, C2, and C3 from the front of the bracket. . . . . ( )

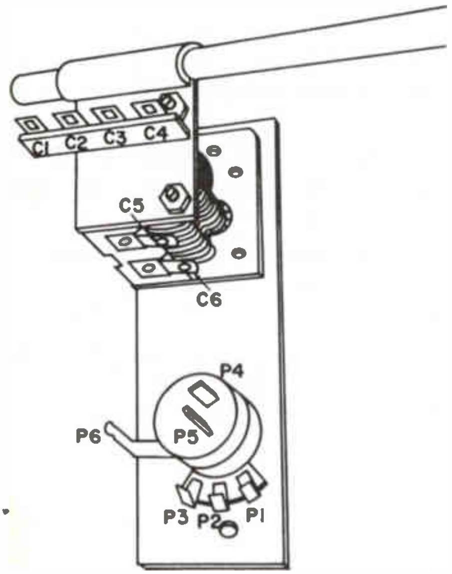

Fig. 9. Parts placement on volume control bracket.

While holding the heads of the three 6-32 screws, slip a 1/4" spacer over the end of each screw. . . . . ( )

Carefully position the tuning capacitor, as shown in Fig. 9, with the two trimmer capacitors nearest hole D. The shaft of the capacitor goes through hole C. . . ( )

Line up the ends of the three screws with the corresponding tapped holes on the front mounting plate of the tuning capacitor. Move the capacitor and bracket together and tighten the three 6-32 screws. . . . . ( )

Make sure the plates of the tuning capacitor are fully meshed. . . . . ( )

To insure safe arrival, the ferrite rod antenna has been shipped to you in three separate parts: the fiber mounting bracket, the ferrite rod, and the antenna coil itself. You will now assemble the three parts of the antenna.

Slip one end of the ferrite rod into the sleeve of the mounting bracket. Position the rod as shown in Fig. 10. . . . . ( )

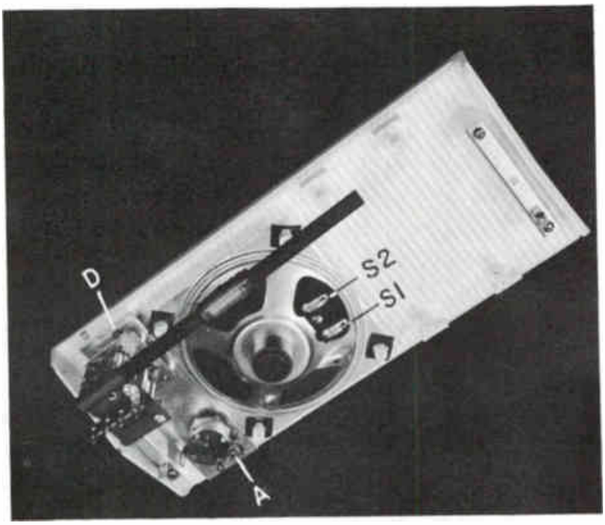

Fig. 10. Parts mounted on front panel.

Examine the antenna coil and notice that there are two separate windings: a small winding and a large winding. Slide the antenna coil onto the ferrite rod with the larger winding nearest the fiber mounting bracket. Figure 10 shows the relative positions of the three parts of the assembled antenna. . . . . ( )

Mount the assembled antenna and four-lug terminal strip to the rear plate of the tuning capacitor as shown in Fig. 9. These parts are fastened with two 4-40 X 1/4" screws and two 4-40 hex nuts in the two small holes near the edge of the rear frame of the tuning capacitor. . . ( )

Final Mounting of Parts on the Front Panel. You will need the following parts in this step of the assembly:

1	Loudspeaker
1	Volume control bracket with parts mounted.
2	No. 6 X 1/4" self tapping screws
4	Loudspeaker mounting clips.
1	Front panel assembly

Place the front panel in front of you on a soft cloth and position the loudspeaker with the speaker lugs S1 and S2 as shown in Fig. 10. . . . . ( )

Push one of the loudspeaker mounting clips over each of the four loudspeaker mounting posts on the front panel. . . ( )

Position the volume control mounting bracket as shown in Fig. 10. . . . . ( )

Fasten the bracket to the front panel with a No. 6 X 1/4" screw in hole A of the bracket. Again, do not overtighten this screw or you may break the plastic mounting post. . . . . ( )

Slip the other No. 6 X 1/4" screw between the tuning capacitor frame and the mounting bracket at hole D. . . . . ( )

Push the screw through hole D and fasten to the front panel. Use a thin-bladed screwdriver to tighten this screw. This will make it easier to clear the capacitor frame. . . . . ( )

You have now completed mounting the parts. Compare your work with Figs. 6, 7, 9, and 10. You are now ready to go ahead with the wiring.

WIRING
THE FILAMENTS
AND B−

In doing the wiring, follow the techniques you have learned. Keep your soldering iron clean and well-tinned, and be sure it is hot when you use it. In connecting hookup wire, remove just enough insulation from the ends to make a hook, and hook the bare end through the terminal lug. Use temporary hook joints in all your connections so that, if you have to disconnect them in the experiments, it will not be so difficult. You will be given instructions on when to solder each connection. Cut the leads of the parts to the proper length, make your wiring neat, and keep the wires and leads short.

For this step you will need black and white twisted wire and hookup wire.

First, prepare two lengths of black and white twisted wire as shown in Fig. 11 and the following instructions.

Cut off a 9" length of twisted wire. ( )

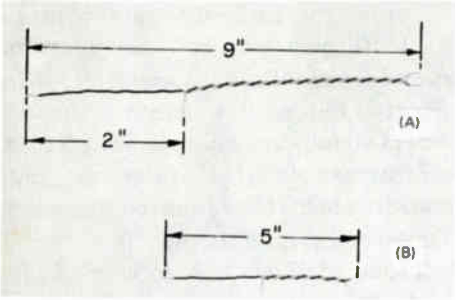

Fig. 11. Twisted filament wires.

Carefully cut only the WHITE wire 2″ from one end. Untwist and remove the short length of white wire and straighten the remaining black wire. . . . . ( )

Cut a 5″ length of twisted wire. . . ( )

Carefully cut only the WHITE wire 2″ from one end. . . . . ( )

Untwist and remove the short length of white wire. . . . . ( )

Now wire the filaments and B– according to the instructions in Table I and the layout of Fig. 12. As you finish each connection, put a check mark in the last column.

PART	FROM	TO	SOLDER	✓
LONG BLACK LEAD OF 9" TWISTED WIRE	3 OF SOCKET R	3 OF SOCKET B	BOTH	✓
WHITE LEAD OF 9" TWISTED WIRE	4 OF SOCKET J	4 OF SOCKET B	BOTH	✓
LONG BLACK LEAD OF 5" TWISTED WIRE	4 OF SOCKET E	3 OF SOCKET N	BOTH	✓
WHITE LEAD OF 5" TWISTED WIRE	3 OF SOCKET J	4 OF SOCKET N	BOTH	✓
HOOKUP WIRE	4 OF SOCKET R	L2	BOTH	✓
HOOKUP WIRE	2 AND CENTER POST OF SOCKET R	CENTER POST OF SOCKET N	2	✓
HOOKUP WIRE	CENTER POST OF SOCKET N	CENTER POST OF SOCKET J	NO	✓
HOOKUP WIRE	CENTER POST OF SOCKET J	3 AND CENTER POST OF SOCKET E	3 OF SOCKET E	✓
HOOKUP WIRE	CENTER POST OF SOCKET E	DB1	NO	✓

Table I. Instructions for wiring filaments and B–.

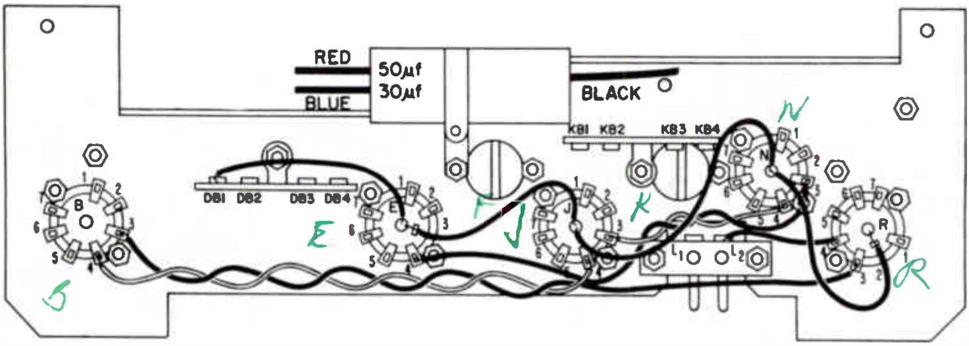

Fig. 12. Pictorial diagram of filament and B– wiring.

PRELIMINARY I-F AND RF WIRING

Next, you will wire the i-f amplifier and parts of the detector and converter stages. Follow the instructions in the layout of Fig. 13 and Table II.

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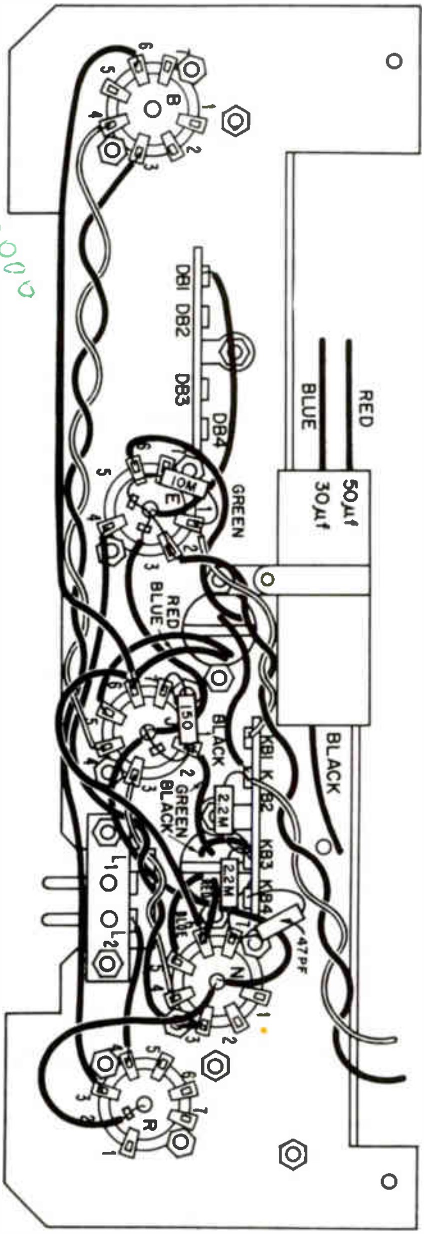

Fig. 13. Pictorial diagram of i-f amplifier and rf wiring.

Before you begin the wiring steps in Table II, you will have to prepare a special length of twisted wire as shown in Fig. 14. Cut a 7-3/4" length of twisted wire. Carefully cut only the white lead at a distance of 2-1/2" from one end. Untwist about 1/2" from both sides of the cut and strip all six ends.

Figure 15 shows how to connect one lead of the 10 meg resistor. Notice that the lead goes through terminal 5, the center post, and terminal 2 of socket E. Also, be sure to leave 1/4" from the body of the resistor to terminal 5.

You will need the following:

1 150-ohm, 1/2-watt resistor
2 2.2-meg, 1/2-watt resistors
1 10-meg, 1/2-watt resistor
1 47 pf capacitor
Twisted wire
Hookup wire

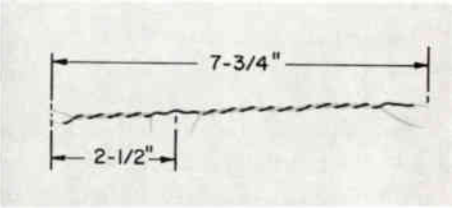

Fig. 14. Prepared twisted wire.

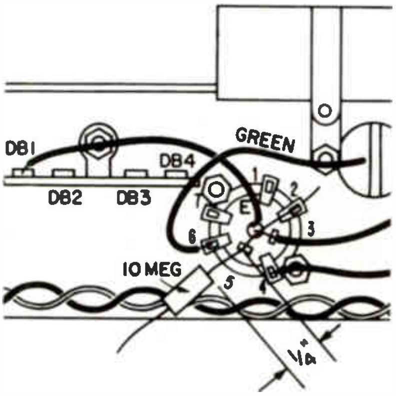

Fig 15. How to mount the 10 meg resistor.

PART	FROM	TO	SOLDER	✓
BLUE LEAD	HOLE K	5 OF SOCKET N	YES	
RED LEAD	HOLE K	6 OF SOCKET N	NO	
GREEN LEAD	HOLE K	1 OF SOCKET J	YES	
BLACK LEAD	HOLE K	KB3	NO	
BLUE LEAD	HOLE F	5 OF SOCKET J	YES	
RED LEAD	HOLE F	6 OF SOCKET J	NO	
BLACK LEAD	HOLE F	KB2	NO	
GREEN LEAD	HOLE F	6 OF SOCKET E	YES	
HOOKUP WIRE	6 OF SOCKET N	6 OF SOCKET J	SOCKET N	
HOOKUP WIRE	6 OF SOCKET J	6 OF SOCKET B	SOCKET J	
2.2 MEG RESISTOR	KB2	KB3	NO	
47 PF CAPACITOR	KB4	7 OF SOCKET N	NO	
2.2 MEG. RESISTOR	KB3	7 OF SOCKET N	SOCKET N	
150 OHM RESISTOR	2 AND CENTER POST OF SOCKET J	7 OF SOCKET J	ALL	
10 MEG. RESISTOR	5,CENTER POST, 2 OF SOCKET E	1 OF SOCKET E	5 AND CENTER POST OF SOCKET E	
SHORT WHITE LEAD OF TWISTED WIRE	1 OF SOCKET E	KB1	SOCKET E	
BLACK LEAD OF TWISTED WIRE	2 OF SOCKET E	-------	YES	
WHITE LEAD OF TWISTED WIRE	KB2	-------	YES	

Table II. Instructions for preliminary wiring of if-rf stages.

WIRING THE POWER SUPPLY AND AUDIO STAGES

Figure 16 shows the wiring layout of the power supply and audio stages.

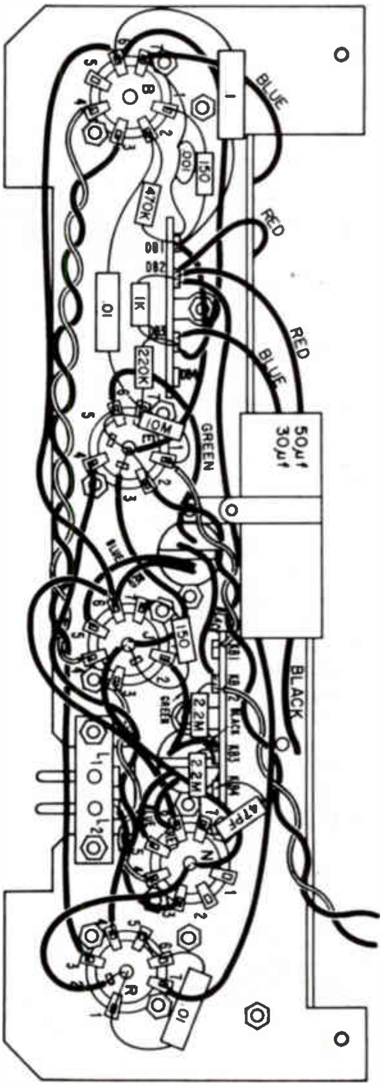

Fig. 16. Wiring layout of the power supply and audio stages.

The parts you will need are:

1 150-ohm, 1/2-watt resistor
1 220k-ohm, 1/2-watt resistor
1 470k-ohm, 1/2-watt resistor
1 1k-ohm, 1-watt resistor
1 0.1 μf capacitor
2 0.01 μf capacitors
1 0.001 μf capacitor
Hookup wire

Follow the instructions in Table III and the layout of Fig. 16 in wiring the power supply and audio stages.

PART	FROM	TO	SOLDER	✓
.01μf CAPACITOR	1 AND CENTER POST OF SOCKET R	5 AND 6 OF SOCKET R	5 AND 6	
HOOKUP WIRE	7 OF SOCKET R	DB2	7	
HOOKUP WIRE	DB3	6 OF SOCKET B	NO	
BLUE LEAD	ELECTROLYTIC CAPACITOR	DB3	NO	
RED LEAD	ELECTROLYTIC CAPACITOR	DB2	NO	
RED LEAD	AUDIO TRANSFORMER	DB2	NO	
1K, 1W RESISTOR	DB2	DB3	DB2	
220K, 1/2W RESISTOR	DB3	7 OF SOCKET E	DB3	
.01μf CAPACITOR	7 OF SOCKET E	2 OF SOCKET B	7	
470K, 1/2W RESISTOR	2 OF SOCKET B	DB1	2	
BLUE LEAD	AUDIO TRANSFORMER	7 OF SOCKET B	NO	
.001μf CAPACITOR	7 OF SOCKET B	DB1	7	
150 OHM,1/2W RESISTOR	1 OF SOCKET B	DB1	1	
.1μf CAPACITOR	6 OF SOCKET B	DB1	BOTH	

Table III. Instructions for wiring the power supply and audio stages.

WIRING THE OSCILLATOR

In this step you will finish wiring the oscillator section. Some of the wiring is on the top of the chassis and some is on the bottom of the chassis.

Figure 17(A) shows the wiring on the bottom of the chassis, and Fig. 17(B) shows wiring on top of the chassis.

You will need:

1 22k-ohm, 1/2-watt resistor
Twisted wire
Hookup wire

Proceed with the wiring instructions given in Table IV and Fig. 17.

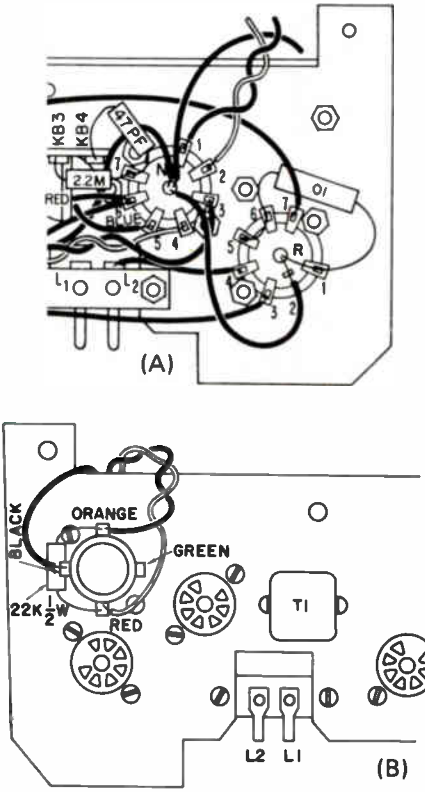

Fig. 17. (A) Wiring on bottom of chassis for the oscillator, and (B) wiring on top of chassis.

PART	FROM	TO	SOLDER	✓
BLACK LEAD OF TWISTED WIRE	1 OF SOCKET N	ORANGE LUG OSC. COIL	1	
WHITE LEAD OF TWISTED WIRE	2 OF SOCKET N	RED LUG OSC. COIL	2	
HOOKUP WIRE	CENTER POST OF SOCKET N	BLACK LUG OSC. COIL	BOTH	
22K, 1/2 W RESISTOR	ORANGE LUG OSC. COIL	RED LUG OSC. COIL	BOTH	

Table IV. Wiring instructions for the oscillator section.

PREPARING THE FRONT PANEL

For this step you will connect some leads to the antenna, switch, and loudspeaker to make final assembly of the receiver easier.

You will need:

- The front panel assembly
- Hookup wire
- Twisted wire
- 1 25 pf capacitor

Figure 18 identifies the four leads of the antenna. Leads 1 and 2 go to the large winding and leads 3 and 4 go to the smaller winding. Do not cut any of these leads. You will need the full length later when you adjust the position of the antenna coil.

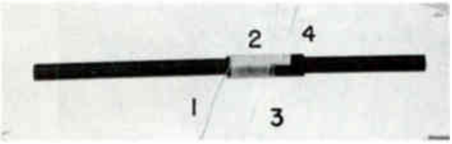

Fig. 18. Lead identification on the ferrite rod antenna.

Instructions are given in Table V. Refer to Fig. 9 and Fig. 19 for wire placement and terminal identification.

PART	FROM	TO	SOLDER	✓
NO. 1 WIRE	ANTENNA	C1	NO	
NO. 2 WIRE	ANTENNA	C4	NO	
NO. 3 WIRE	ANTENNA	C2	YES	
NO. 4 WIRE	ANTENNA	C3	YES	
HOOKUP WIRE	C1	C6	C1	
4-1/2" LENGTH HOOKUP WIRE	C6	------	YES	
25PF CAP.	C4	C5	C4	
1-3/4" LENGTH HOOKUP WIRE	C5	------	YES	
WHITE LEAD OF 5" LENGTH OF TWISTED WIRE	S1	------	YES	
BLACK LEAD OF TWISTED WIRE	S2	------	YES	
3-1/2" LENGTH HOOKUP WIRE	P4	------	YES	

Table V. Instructions for wiring the front panel.

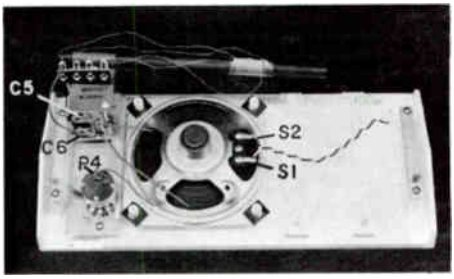

Fig. 19. Front panel wiring.

FINAL ASSEMBLY

In this step you will join the front panel and the chassis and complete the wiring. You will need the following:

Partially wired chassis
Front panel

1	100 pf capacitor
1	0.01 μf capacitor
1	0.05 μf capacitor
1	0.1 μf capacitor
1	No. 6 solder lug
2	6-32 X 1/4" screws

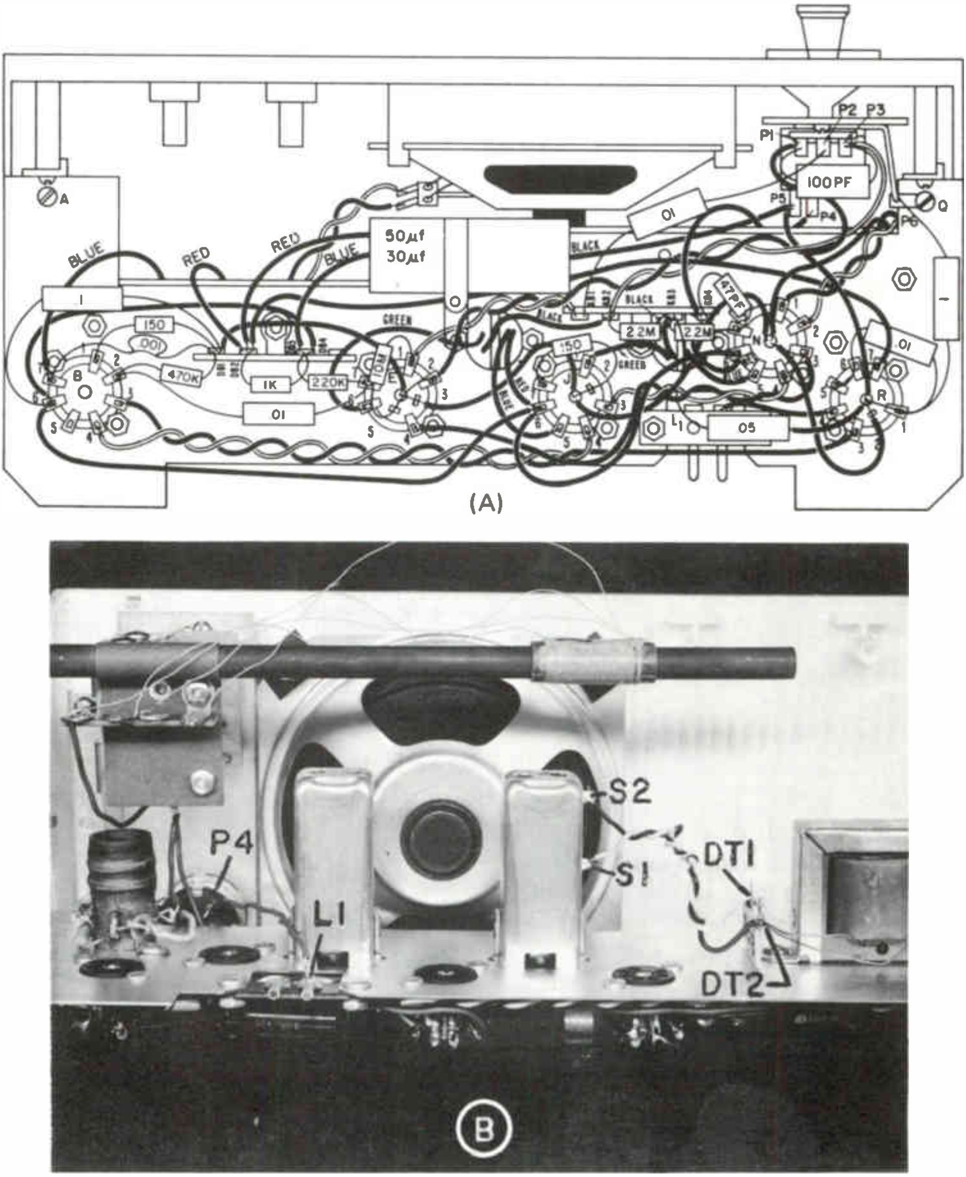

Fig. 20. (A) Chassis and panel assembled and wired, (B) final assembly.

2 6-32 hex nuts
2 No. 6 lockwashers
1 Insulated sleeving

Figure 20(A) shows how the chassis and panel go together, as well as the placement of wires and parts under the chassis. Figure 20(B) shows the wiring on top of the chassis.

Insert one of the 6-32 X 1/4" screws through hole A of the chassis from the bottom. Position the chassis and panel as shown in Fig. 20(A). Push the 6-32 screw on through the hole in the protruding spade bolt on the chassis support bracket and fasten with a No. 6 lockwasher and one of the 6-32 hex nuts. .... ( )

Insert the other 6-32 X 1/4" screw through the large hole in the No. 6 solder lug. .... ( )

With the solder lug facing toward the volume control, push the 6-32 screw through hole Q of the chassis and the hole in the spade bolt on the chassis support bracket. .... ( )

Fasten in place with a No. 6 lockwasher and the remaining 6-32 hex nut. ( )

Bend the solder lug so it is touching the ground lug P6 of the volume control. Both lugs together are now P6. ..... ( )

Next, complete the assembly of your receiver following the instructions in Table VI. Figure 20 shows parts placement.

This completes the wiring of your receiver. Before plugging in the tubes and turning the set on, carefully inspect all connections on the chassis. Every connection should be well soldered, with no

PART	FROM	TO	SOLDER	✓
WIRE	P4	L1	YES	
WIRE	C6	KB4	YES	
WIRE	C5	GREEN LUG OSC. COIL	YES	
BLACK LEAD	S2	DT2	NO	
WHITE LEAD	S1	DT1	NO	
ENAMEL WIRE	AUDIO TRANSFORMER	DT2	YES	
ENAMEL WIRE	AUDIO TRANSFORMER	DT1	YES	
05μf CAPACITOR WITH SLEEVE	KB3	CENTER POST OF SOCKET R	KB3	
BLACK LEAD	ELECTROLYTIC CAPACITOR	P5	NO	
HOOKUP WIRE	P5	CENTER POST OF SOCKET R	BOTH	
100 RF CAPACITOR	P1	P3	NO	
WHITE LEAD	KB2	P3	YES	
BLACK LEAD	2 OF SOCKET E	P1	YES	
.01μf CAPACITOR	P2	KB1	BOTH	
.1μf CAPACITOR	1 OF SOCKET R	P6	BOTH	

Table VI. Instructions for the final wiring of the receiver.

stray wires shorting to other terminals. Lug DB4 should be the only lug which has no connections made to it. Compare your wiring with that in the figures. Parts must be positioned exactly as shown in order for the chassis to fit easily inside the cabinet. One of the best ways of checking your wiring is to have someone else go over it.

When you are certain that you have made no mistakes and that all connections are securely soldered, insert the five tubes in the following sockets:

50C5	in socket B
12AT6	in socket E
12BA6	in socket J
12BE6	in socket N
35W4	in socket R

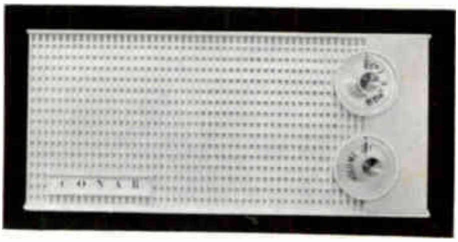

Fig. 21. Front of receiver with knobs in place.

With the tuning capacitor shaft turned fully clockwise (plates meshed) and the volume control fully counterclockwise (switch off), push the knobs on as shown in Fig. 21.

Take the power cord and mate it with the interlock connector prongs, L1 and L2.

Testing and Analyzing the Receiver

Before you start your experiments, you will make tests on your receiver to see that it is operating properly. Refer to the complete schematic diagram shown in Fig. 22 to locate terminals and parts.

PRELIMINARY TESTS

Receivers brought to the shop for repair work, as well as new equipment such as the receiver you have just constructed, should be tested before being placed in operation. Defects in the receiver may ruin parts if the set is plugged in and turned on without these preliminary tests.

If you have faithfully followed all instructions and the quality of your workmanship is good, it would probably be safe to turn on the set. However, you should not take a chance that everything is all right. A simple test and an inspection lasting a few minutes will tell you if it is safe to apply power to the set, so wait until you have carried out the tests suggested in this section.

The greatest danger is from a short in the B supply system, which might damage the rectifier tube.

The easiest way to work on the receiver so that you can perform the following experiments is to stand it up on one end with the tuning capacitor and volume control nearest the work table. You will then have easy access to both the top and bottom of the chassis.

First, set your tvom for high-range ohmmeter measurements, and connect the ground clip to pin 1 of the 35W4 and the probe to the cathode, pin 7 of the 35W4 tube socket. The meter pointer will indicate a low resistance because the filter capacitors are discharged. As the 1.5-volt cell in the ohmmeter section of the tvom gradually charges up the capacitors, the pointer will rise, indicating higher and higher resistance. In about two minutes the reading will reach its maximum. The resistance measured should not be less than 150,000 ohms. If the reading is lower than 100,000 ohms, there is certainly a short in the B+ circuit which you must locate and remove before trying the set out; otherwise the 35W4 may be ruined.

If you do measure abnormally low resistance, look for bare parts leads that are shorting to other terminals or leads, look for solder that has dropped from one terminal to another or to the chassis, and then check the wiring against Fig. 22. If you don't find anything wrong, disconnect the positive leads of the electrolytic capacitors one at a time. If the reading goes up when a capacitor lead is disconnected, that capacitor is leaky and must be replaced.

If your test shows that the resistance is normal, it is safe to try out the set.

Notice that there is a trimmer capacitor on top of each tuning capacitor section. The one toward the front (nearest the front panel) is the rf trimmer; the other is the oscillator trimmer. Before turning on the receiver, use a screwdriver to tighten the screw on each trimmer as far as it will go in the clockwise direction.

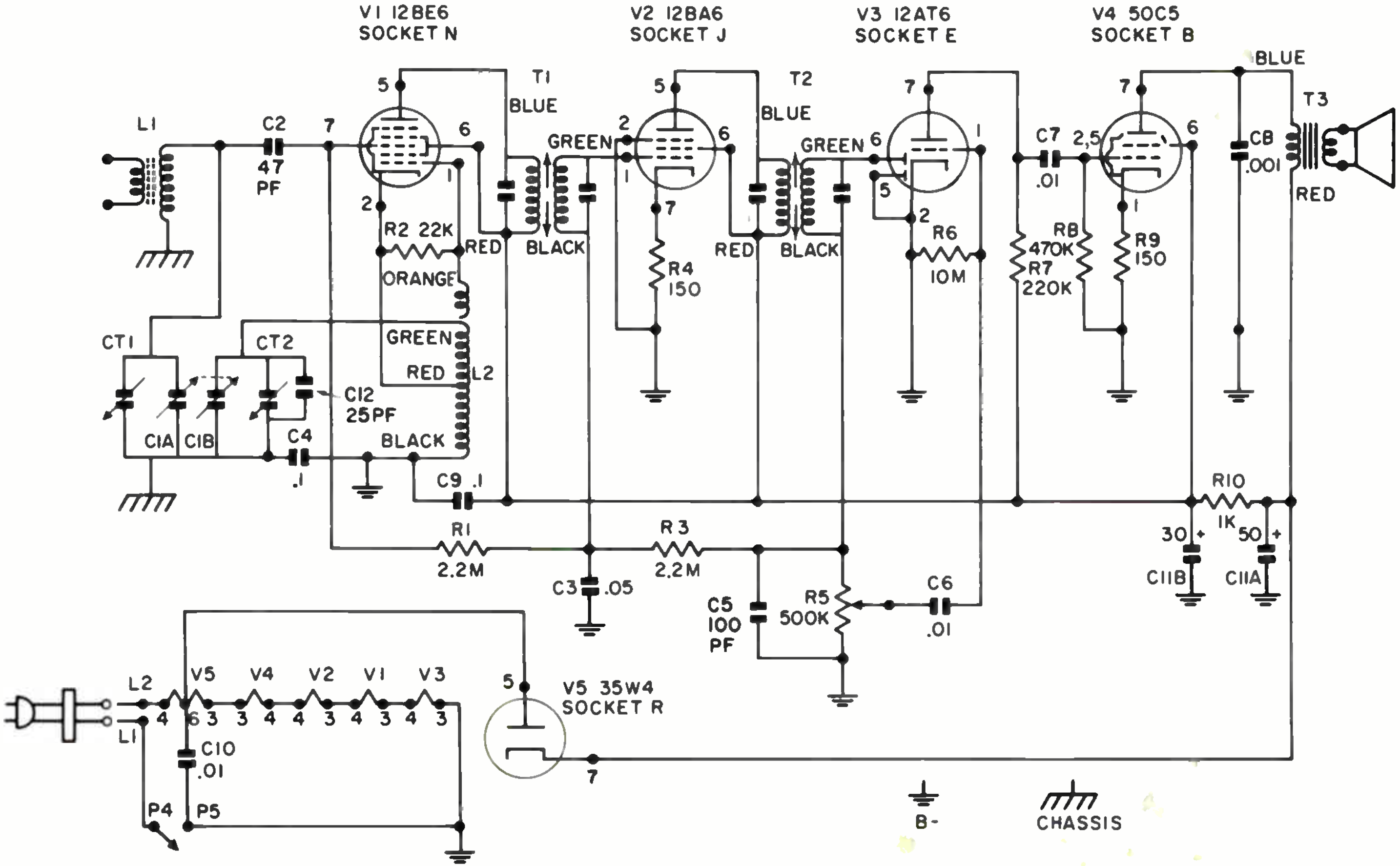

Fig. 22. Schematic diagram of the 7YY receiver.

Insert the power plug into the wall outlet and turn the set on. Turn the volume control all the way clockwise, and tune the receiver across the dial. If you are near stations, you should be able to pick one up somewhere near the high-frequency end of the dial around 1400 kHz or 1500 kHz. (Notice that the final two zeros have been omitted from each of the dial numbers; for example, 1400 kHz is at 14 on the dial.) The station will probably not come in at the proper dial setting. Identify the station by picking it up on another receiver, or by waiting for a station announcement. Then, tune your receiver to the correct dial setting for that station.

Adjust the oscillator trimmer CT2 very carefully until you receive the station again, this time at the proper dial setting. CT2 is the trimmer on top of the tuning capacitor farthest from the front panel. CT1 is the trimmer closest to the font panel. Next, adjust the rf trimmer CT1 for maximum volume. You should then be able to pick up a number of stations at their correct dial settings.

To get a better adjustment of the rf trimmer, connect your dc voltmeter across the volume control, with the ground clip to terminal P1 and the probe to terminal P3 of the volume control. Set the Function switch for -DC voltages, and choose a range setting that gives an appreciable reading when the set is tuned to a station near the high-frequency end of the dial. Now adjust the tuning dial for maximum voltage, even though you have to shift the dial setting slightly. Now, adjust the rf trimmer for maximum voltage across the volume control. You should be able to pick up stations at various points on the dial.

Tune in a station near the middle of the dial. Slowly slide the antenna coil up and down on the ferrite rod until the signal is maximum. This adjustment will increase the sensitivity of your receiver by correctly matching the antenna to the input circuits of the receiver.

The i-f transformers have been preset at the factory, and should need little adjustment. However, because of variations in parts values and tube characteristics in the diode detector circuit, the second i-f transformer may need some adjustment. Follow the procedure very carefully, making only the adjustments you are told to make.

Leave the tvom connected between terminals P1 and P3 to measure the avc voltage, and tune the receiver to a station near the high-frequency end of the dial. Now, refer to the top view of the chassis, Fig. 7, and find the second i-f transformer, T_2. You are to peak each slug for maximum avc voltage as indicated on the meter. Use the alignment tool (AT3) provided. Note that there are two slugs in each of the i-f transformers; one adjusts the resonant frequency of the primary winding, and the other affects that of the secondary. Turn the top slug from the top of the chassis, and the bottom slug from the wiring side. Insert the alignment tool only far enough to reach the closer slug.

DO NOT ADJUST THE SLUGS IN THE FIRST I-F TRANSFORMER. You will make these adjustments later when you do the experiment on alignment. If you adjust them now, you may get the receiver so far out of alignment that you will need a signal generator to realign it.

Carefully turn each slug a very small amount to the right and to the left of its original setting, until the avc voltage is at maximum. This adjustment is critical; usually a fraction of a turn is enough.

When you have peaked the top slug for maximum avc voltage, repeat the adjustment on the bottom slug in the same way. Your receiver should now operate satisfactorily. Do not attempt to make any further adjustments until you are told to do so.

If your set does not work and you write for help, let us know if the tubes light, and if there is a loud buzz from the speaker when you touch the control grid of the 12AT6 tube with your finger. Even if your set does not work, take the voltage and resistance measurements as instructed in the next section, and let us know the results. This will help us to diagnose your trouble.

TAKING VOLTAGE AND RESISTANCE MEASUREMENTS

Point-to-point voltage and resistance values are given in most manufacturers' service diagrams. If you cannot diagnose a defect by observing the symptoms, or cannot localize it, you can sometimes find the trouble by checking the resistance and voltage values and comparing them with the published values. Your values and those given by the manufacturer will not necessarily match, but with experience you will be able to decide if the variations are normal.

TUBE	VOLTAGE	PIN 1	PIN 2	PIN 3	PIN 4	PIN 5	PIN 6	PIN 7
V1 12BE6	TYPICAL	-11V DC	0	11.2V AC	21.7V AC	+84V DC	+85V DC	-.27V DC
	YOURS	0	+.84	10.6	23	93	93	-.28
V2 12BA6	TYPICAL	-.35V DC	0	21.5V AC	33V AC	+84V DC	+85V DC	+1.15V DC
	YOURS	-.36	0	22	32	105	97	1.4
V3 12AT6	TYPICAL	-.75V DC	0	0	11.2V AC	0	-.5V DC	+46V DC
	YOURS	-.67	0	0	10.8	0	-.52	52
V4 50C5	TYPICAL	+4.8V DC	0	75V AC	33V AC	0	+84V DC	+90V DC
	YOURS	5.8	0	76	32		77	96
V5 35W4	TYPICAL	0	0	75V AC	118V AC	98V AC	98V AC	+104V DC
	YOURS	0	0	78	108.5	102	103	106

Fig. 23. Voltage values for the 7YY receiver. Record the voltages you measure below the typical values.

PIN	V1-12BE6		V2-12BA6		V3-12AT6		V4-50C5		V5-35W4	
TVOM GROUND TO B−										
1	22K	22k	2.7M	4M	10M	10M	150Ω	120	0 Ω	0
2	1.2Ω	1.0	0 Ω		0Ω		470K	460k	0 Ω	6
3	19Ω	30	28Ω	45	0Ω		82Ω	112	80Ω	130
4	31Ω	50	39Ω	60	16Ω	20	35Ω	50	120Ω	200
5	—		—		0Ω		470K	500k	110Ω	180
6	—		—		500K	430K	—		110Ω	180
7	5M	6M	150Ω	110	—		—		—	
TVOM GROUND TO B+										
5	1K	1K	1K	1K	—		—		—	
6	1K	1K	1K	1K	—		1K		—	
7	—		—		220K	200k	400Ω	300	—	

Fig. 24. Resistance values for the 7YY receiver. Record your values beside the typical ones.

Typical voltage values for the 7YY receiver are given in Fig. 23 and typical resistance values are given in Fig. 24. Make your own measurements and record them regardless of whether your set is working properly or not.

Remember that for voltage measurements, the set must be plugged into the power line. Since this is an ac-dc set, connect the meter ground clip to pin 1 of the 35W4, which is at B−. Do not connect it to the chassis. Tune the receiver to the high-frequency end of the dial at a point where no station is coming in when you take the voltage measurements.

When taking resistance readings, be sure that the receiver is disconnected from the power line. Notice that for some resistance measurements the ground clip is to be connected to B−, and for some it is to be connected to B+. Use pin 7 of the 35W4 as the B+ connection. Measure your resistances, and record them in Fig. 24 so you will have them for future use. If you were servicing a receiver, you would not write down your results, but would compare each measurement with the manufacturer's listed reading as you made it.

The charts in Figs. 23 and 24 show where to place the probe for each measurement, and the typical value indicates which range to use. Note that some of the voltages measured are negative, some positive, and some ac. In the resistance measurements, an infinity reading means that the resistance is too high to be measured. The reading from B− to pin 7 of V5 depends upon the condition of C11A and C11B, and how long the test leads are attached to the circuit.

In your service work, you may notice some unusual effects when taking resistance measurements in a radio or TV set. As you have learned, resistance measurements are always made with the receiver disconnected from the power line. Sometimes, if a resistance measurement is made immediately after the equipment being tested is unplugged from the line, the cathodes of the tubes will still be hot and will still be emitting electrons. This will affect the ohmmeter readings and will cause completely erroneous results. You can easily demonstrate this.

With the receiver operating, connect the ground clip of your tvom to B–, and set up the tvom for ohmmeter measurements. Remove the plug from the wall outlet, and quickly touch the probe to mixer grid pin 7 of the 12BE6 tube. Again notice that the reading is very low. Leave the probe connected and watch the meter pointer. The pointer will gradually rise until you measure approximately 5 megohms. The reason for these peculiar results is that the cathode of the 12BE6 tube was still hot and was continuing to emit electrons. When the tvom is used as an ohmmeter, the probe is positive, and connecting it to the mixer grid made the mixer grid positive, and electrons flowed from the cathode to the mixer grid and through your tester.

If you had reversed the meter connections, placing the ground clip on pin 7, and the probe on B–, you could have measured the true circuit resistance before the tube cooled off. It is not necessary to do this, however, because tubes will cool rather quickly. In servicing radio or TV receivers, be on the lookout for the ohmmeter actions that you have just demonstrated so that you will not be confused by them.

ANALYZING THE RECEIVER

The i-f transformers between the 12BA6, 12BE6, and 12AT6 tubes, and the oscillator circuit used with the 12BE6 tube, identify this set as a superheterodyne.

The Power Supply. The diagram shows that this is an ac-dc receiver. We know this because there is no power transformer. Since there is a half-wave rectifier connected to the power line, a B supply voltage could be obtained from either an ac or a dc power line. On dc, the plug must be inserted so that a positive voltage is applied to the plate of the rectifier. The tube filaments in series across the power line can also be supplied from either an ac or a dc source.

In the filament circuit, the sum of the filament voltages required by the various tubes is 12 volts + 12 volts + 12 volts + 50 volts + 35 volts, or 121 volts. Since the average power line will furnish between 112 and 120 volts, each tube will receive approximately its rated filament voltage. Even a large variation in line voltage will have little effect on cathode heating, since the tube filament voltages are not at all critical.

The 35W4 tube functions as a half-wave rectifier. However, the plate of the tube, instead of being connected directly to one side of the power line, is connected to a tap on its own filament. This means that the plate current of the 35W4 flows through the top part of the filament, connected to pins 4 and 6. The resistance of this filament section will protect the B supply in case of a short by limiting the plate current of the tube. Excess current, however, will burn out the filament between pins 4 and 6.

Signal Circuits. Let us follow a signal through the receiver. Radio signals in the air induce a voltage in the ferrite rod antenna, L1. At the resonant frequency (the frequency to which the receiver is tuned), determined by the values of L1 and tuning capacitor C1A, resonance step-up occurs, and a large signal appears across the tuning capacitor C1A. This signal is applied through C2 to the mixer grid, pin 7 of the 12BE6 tube, and through capacitor C4 and the red and black taps on the oscillator coil to the cathode. This signal, acting between the mixer grid and the cathode, modulates the electron stream flowing from the cathode to the plate. At the same time oscillation occurs in the 12BE6, and the oscillator signal at oscillator grid 1 also modulates the plate current electron stream.

The oscillator circuit that is used is standard. It is the same one you have used before. Coil L3 is not actually an inductance, but serves to give capacity coupling between the oscillator grid (pin 1) and L2 which is the oscillator tank coil. An actual capacitor could have been used just as well. The frame of the tuning capacitor is connected to the chassis, and in order to complete the circuit from the black lead of the oscillator coil to the tuning capacitor, we install capacitor C4. This also completes the path in the resonant circuit of L1 and C1A. The fact that the capacitor is common to both resonant circuits is of little importance. If some of the oscillator signal is injected directly into the mixer grid circuit, no harm will result. The two signals are mixed in the tube and the resulting beat signals and the original signals flow through the primary of the first i-f transformer, T1. The primary winding is tuned to the intermediate frequency, which is the difference between the incoming signal and the local oscillator signal. Since the reactance is low at off-resonance frequencies, such signals pass through the transformer primary without inducing an appreciable voltage in the secondary, and are bypassed to B− through C9 and C11B. Ordinarily C11B would be all the bypass required, but it is an electrolytic capacitor, and because of its construction, not effective for bypassing high-frequency signals, particularly when it has been in use for a long time. C9, on the other hand, is an excellent rf bypass, and is ready to take over if C11B (because of an increasing power factor) does not bypass the rf signals.

The secondary of T1 is tuned to resonance at the desired frequency so that when the desired signal is applied to the primary, a corresponding signal is induced in the secondary. It is applied directly to the control grid of the 12BA6, and through C3 and R4 to the cathode of the tube. Remember that a signal must always be applied between the control grid and the cathode. Just tracing the signal to the grid is not enough.

Resistor R4 has a value of only 150 ohms, so very little voltage is developed across it. However, the resistor is not bypassed, and the voltage developed across it will be of such a polarity as to oppose the signal voltage. The resulting degeneration tends to make the stage stable and to prevent oscillation.

The 12BA6 tube amplifies the signal, and the amplified signal appears across the primary of the second i-f transformer, T2. The action of this resonant circuit is to boost the i-f signal and remove all others that may still be present in the plate circuit of the 12BA6. The signal induced in the secondary undergoes further selection, and is applied to diode plate, pin 6, of the 12AT6, and through C5 to the cathode.

When the i-f signal makes the diode plate negative, no current flows through the tube, but when the i-f signal makes the diode plate positive, electrons flow from the cathode to diode plate 6, through R5 and back to the cathode. A voltage drop appears across R5. Since the current flows only when the plate is positive, rectification or detection results, and we have the audio across resistor R5.

The dc component across R5 is used for avc purposes. To get a pure dc voltage, the audio voltage that is also present across the volume control must be filtered out. This is done by means of R3 and C3, and only the dc voltage appears across C3. The dc voltage is applied to the mixer grid of the 12BE6 and the control grid of the 12BA6. If the signal increases, the voltage across R5 also increases, and the gain of the 12BE6 and 12BA6 tubes decreases. On the other hand, if the signal tends to fade, less voltage will appear across R5, and the gain of the 12BE6 and 12BA6 tubes will increase. Any part of the available audio voltage across R5 can be applied to the control grid and cathode of the 12AT6 tube. The part that is applied depends upon the setting of R5, which is the volume control. The connection to the control grid is through C6, and the cathode connection is direct, since the lower end of the volume control is in electrical contact with the cathode.

The 10-megohm resistor R6 is used to bias the control grid of the 12AT6 tube. The tube amplifies the signal applied to its control grid-cathode, and the amplified signal appears across the plate load resistor R7. This signal is applied to the control grid -- pin 2 or pin 5 of the 50C5, and through output filter capacitor C11B and resistor R9 to the cathode of the 50C5. Again amplification occurs, and this time large amounts of power are developed across the primary of output transformer T3. Voltage is induced in the secondary, and the resulting current flow through the voice coil sets the cone in motion, thus reproducing the sound waves which were picked up by the microphone at the broadcasting station.

The bias voltage for the output tube V4 is obtained from the voltage drop across the 150-ohm resistor, R9, in the cathode circuit. The bypass capacitor, C8, in the plate circuit is used to make the plate circuit capacitive so that the tube will not go into oscillation at high frequencies, which may be beyond the audible range. As long as the plate circuit is capacitive, oscillation will not take place.

Notice that capacitor C10 is connected directly across the power line. The purpose of this capacitor is to prevent rf signals from entering the receiver by way of the power line, and causing hum modulation. If there are poorly soldered connections somewhere in the power line, the 60 Hz power line signal could modulate the rf signal, resulting in an annoying hum, Bypassing the signal before it can get into the receiver circuit prevents hum modulation, because then only the signal induced in the loop will be amplified, detected, and reproduced by the loudspeaker.

Although the foregoing description is brief, it should give you an idea of how your receiver works and how the various parts work together. Study the several sections of the receiver carefully to become more familiar with the operation of the receiver.

Performing the Experiment

The ten experiments in this manual are designed to give you practical experience in servicing all types of sets, not just ac-dc sets.

In the first two experiments, you will learn to isolate trouble to one section of the receiver. In the later experiments you will demonstrate symptoms produced by defects you will frequently find, and you will learn the test procedures to follow in finding each defect. You will conduct experiments covering the following major defects:

1. Dead receiver.
2. Hum.
3. Noise.
4. Oscillation.
5. Distortion.
6. Weak reception.
7. Misalignment.

EXPERIMENT 61

Purpose: To show that a meter can be used to indicate the presence or absence of signals in certain stages of the receiver.

Introductory Discussion: When a set is dead, the expert serviceman will need to make only a few tests to find the defective section or stage. There are two basic methods of finding a stage that does not pass a signal. You can tune to a station so that a signal is applied to the input of the dead stage. If the signal is strong enough, you can use the tvom to see if the signal is present at both the input and the output of the stage. In receiver stages where the signal is too weak to be identified with a tvom, the technician must use a more sensitive instrument, such as a signal tracer (described in your regular lessons), or he must use some other method of testing the suspected stage.

In this experiment, we will deal with the first method: identifying the signal with the tvom where possible. We will also point out where it is not possible to use the tvom. The experienced technician will know the limitations of various instruments and will know when it is necessary to turn to other methods of diagnosis. These experiments will give you valuable experience in using test instruments and in carrying out standard troubleshooting procedures. Refer to the schematic diagram in Fig. 22 as you carry out the various tests so that you will become more familiar with the receiver and get more experience in reading diagrams of this type.

Experimental Procedure: To conduct the steps in this experiment, you need only the receiver in operating condition and the tvom.

Step 1: To show how the tvom can be used to localize a defect causing a dead set to one section of the receiver.

As you know, there are two signal-handling sections in a radio receiver -- the rf and the af sections. The dividing point is the output of the second detector, which is considered a part of the rf section.

Tune in a strong local station, and short the loudspeaker voice coil to kill reception by soldering a short piece of bare hookup wire across the voice coil terminals. Now turn the volume control all the way clockwise. If you hear any of the program, it will be extremely weak.

Now connect the ground clip of the tvom to B- and set the Function switch for -dc voltage. Touch the probe to terminal P3 of the volume control. You should measure a small voltage. Adjust the tuning knob throughout its range. Notice that the voltage drops as you tune away from the station, and that it reappears as you tune past other stations. The presence of this voltage proves that a signal is reaching the second detector, so you know the rf section is working normally. The fact that the rf section works is also proof that the power supply is all right.

Step 2: To trace the signal through the af system with the tvom.

First tune to a point on the dial where a large diode load voltage, measured across the volume control as in Step 1, is produced. Now switch the tvom for ac voltage measurements, and leave the ground clip on B-. Touch the probe to terminal P3 of the diode load resistor (the volume control).

There will be a very small voltage, which can be identified as an audio signal, by noting that it disappears when you tune away from the station. Also, notice that the meter pointer fluctuates. Tune the signal back, and touch the probe to the control grid, pin 1 of the 12AT6 tube. You should measure as much signal here as at the diode load. Lack of signal would indicate an open in coupling capacitor C6.

Move the probe to plate socket pin 7 of the 12AT6 tube; reset the Range switch if the meter pointer goes off scale. You should measure an increased voltage. If the voltage is not larger here than it was on the grid, or if there is no voltage at all on the plate, you know that there is a defect somewhere in the 12AT6 tube circuit. Move the probe to the grid of the 50C5, pin 2. You should measure as much voltage as at the plate of the 12AT6. Lack of signal voltage at the 50C5 grid would indicate an open in coupling capacitor C7.

To see if the signal is present at the output of the 50C5, touch the probe to plate pin 7. You will have to switch to a higher voltage range, because a large signal voltage is present at this point. Since we have a signal at the plate of the 50C5, but no reception, the defect would have to be in the voice coil-output transformer secondary circuit.

In service work, you will probably never find a defective output transformer secondary or a shorted voice coil. Most defects in this part of the receiver are caused by open voice coils. Since the voice coil is in parallel with the transformer secondary, it is necessary to disconnect one lead of the transformer secondary to check the secondary and voice coil individually for continuity. If there is no continuity, there is an open in the part under test.

Let us see why it is necessary to disconnect one of the leads. Turn off the receiver, and remove the piece of wire you soldered across the voice coil terminals. Then, set up your tvom for ohmmeter measurements, using the lowest range. Connect the test leads across the voice coil terminals. You will measure about 0.4 ohm. Now disconnect one of the transformer secondary leads from the voice coil, and check directly across the secondary winding. Move the transformer lead back to the voice coil connection, and you will see that there is no appreciable change in resistance reading with the voice coil in or out of the circuit. These readings are definite proof that to check a voice coil for an open, you must disconnect one of its leads so it can be checked by itself.

Step 3: To show that the tvom is not satisfactory for tracing signals in the rf section.

Resolder the transformer lead to the voice coil terminal, tune in a strong station, and turn the volume control down.

Clip the ground lead of the tvom to B– and set the tvom for ac voltage measurements. Measure the i-f signal at plate pin 6 of the 12AT6 tube. Identify this as an i-f signal by tuning back and forth across the station frequency, noting that the signal voltage is at a maximum when you tune in the station. Now move the probe to the plate, pin 5, of the 12BA6. You should get a little more signal here than at the 12AT6 diode plate. The transformer coupling between the stages, of course, is the reason that the signal is reduced. If the signal is present at the 12BA6 plate, but not at pin 6 of the 12AT6, you would look for trouble in the second i-f transformer.

Now move the probe to the control grid of the 12BA6, pin 1. The signal at this point will be too weak to give a usable indication on the tvom. This means that the tvom is of little value as a signal tracer in the rf section of a receiver. As a matter of interest, however, touch the probe to plate pin 5 of the 12BE6. Since you measured practically no i-f signal voltage at the 12BA6 control grid, you wouldn't expect to measure an i-f signal at the 12BE6 plate. However, you will find a readable rf voltage at the 12BE6 output. This is not an i-f signal, but consists mainly of the oscillator signal, which is present in the mixer plate circuit. Its absence at the 12BA6 control grid shows the effectiveness of the i-f transformer in rejecting undesired signals.

Discussion: The fact that you can trace signals fairly well in the af section of a receiver does not mean that you should use this method to the exclusion of all others. Use it when you start doing service work, along with other test procedures. Then, you will be able to decide whether you like it well enough to use it every time you service a dead set, or whether to use it only on those occasions where other methods leave you in doubt as to the results.

As a matter of fact, an expert technician seldom uses one test procedure exclusively. He knows many test methods, and uses the one that he thinks from experience will best solve the particular problem at hand.

In this experiment, you did not get much output when you measured the i-f signal voltages because the capacity of the tvom probe detuned the circuit. If you were to tune the receiver first for maximum signal strength, then connect the probe, and reset the tuning slug of the i-f section in question, you would measure a larger signal. However, when you removed the probe, you would have to readjust the tuning slug for maximum output. If the set is dead to start with, adjusting the tuning slug might cause trouble. We do not suggest that you attempt it on your receiver, because if you get the i-f badly misaligned, you may have trouble in realigning it.

Instructions for Statement 61: In this experiment you saw that it was necessary to unsolder the output transformer secondary lead from the voice coil terminal to see if the voice coil was open. You did not measure the dc resistance of the voice coil, but from the effect you noted in checking the resistance of the transformer secondary with the voice coil in and out of the circuit, you should be able to complete the statement. If you are not sure, check the voice coil resistance with your ohmmeter. Then, answer the statement here and on the Report Sheet. Resolder the output transformer lead to the voice coil terminal before going on to the next experiment.

Statement No. 61: The resistance of the voice coil is:

[✓ *(1) more than*]
(2) less than
(3) the same as

that of the output transformer secondary.

EXPERIMENT 62

Purpose: To show how to use a circuit disturbance test to find the defective stage.

Introductory Discussion: A signal-injection test is based on the fact that if a signal injected into a certain stage produces a noise in the loudspeaker, you know that all stages between the point where the signal is injected and the loudspeaker must be in operating condition. There are several ways to carry out the test. You can start from the input of the receiver and work toward the loudspeaker, or you can start from the power output stage and work toward the input. In either case, the stage preceding the live point nearest the input is defective. A live point is one where an injected signal produces a sound in the loudspeaker.

When we speak of injecting a signal, we usually think of feeding an audio signal into the af section, and a modulated rf signal into the rf section. To inject such signals would require an af-rf signal generator. These are in common use and are found in most service shops. However, the experienced technician seldom uses them for signal injection when checking a dead receiver, because there is a faster, simpler way to do the job. This is the circuit-disturbance test, which requires only a screwdriver or no tool at all. Your body picks up some 60 Hz ac from the house wiring, so if you touch the input of a high gain audio amplifier with your finger, a 60 Hz signal will be heard in the loudspeaker.

Similarly, if you touch the input of an rf or i-f stage, there will be a slight change in the tube plate current. If there are tuned circuits, they will be shock-excited, and a signal voltage at the resonant frequency will be produced for a few cycles. The strength of this signal will fall off rapidly. This change in amplitude is a modulation on the signal, which can be detected and passed through the audio amplifier to the loudspeaker, where it produces a thud or click. By disturbing the circuit in this way, you can quickly localize trouble to a stage in the receiver, and then use your tvom to locate the defective part.

In this experiment, you will practice circuit disturbance testing.

Experimental Procedure: The only parts that you will require are your receiver in operating condition, your tvom, and your hand tools.

Step 1: To show that a sudden change in current through the output transformer primary will produce a click in the loudspeaker.

Unplug the receiver from the power line, and set up your tvom for low-range ohmmeter measurements. Clip the tvom ground lead to the screen, pin 6, of the 50C5 tube. Tap the probe against plate pin 7. This will cause a slight current to flow through the primary of the output transformer, and you will get a click from the loudspeaker each time the circuit is opened and closed. Use the lowest range of your ohmmeter when doing this, because on the higher ranges, the current flow will be limited, and you may not hear the click.

This shows that only a slight change in current through the transformer primary is necessary to produce a click in the loudspeaker. This procedure can be used to check output transformers and voice coils of pm loudspeakers. Now remove the ground clip from pin 6 of the 50C5 tube socket.

Step 2: To show that a change in the plate current of the output tube will produce a click in the loudspeaker.

Plug in the set, turn it on, and let it warm up. Have the volume control turned down all the way so radio programs will not interfere with the test.

Use a screwdriver that has a long thin blade, and hold it so that your hand is in contact with the metal blade. If you hold the screwdriver by its insulated handle, you may not get a click from the loudspeaker when you carry out the tests. Scrape the end of the blade across pin 2 of the 50C5 or on the lead of resistor R8 that is connected to pin 2. You will hear a noise in the loudspeaker. If you cannot definitely hear a noise or click, momentarily short pins 1 and 2 of the 50C5 together with the screwdriver blade. This will remove the bias from the 50C5, and the speaker will produce a loud click.

Move the blade of the screwdriver to plate pin 7 of the 12AT6 tube. You should again hear a click when the blade touches the plate terminal, if coupling capacitor C7 is in good condition. Do not touch the chassis or the other parts of the receiver when the blade touches the 12AT6 plate, or you will be shocked. However, be sure you have your hand in contact with the blade when you touch the tube socket pin.

Make sure that the 12AT6 is working by touching its control grid, pin 1, or any lead from pin 1. If your hand is in contact with the screwdriver blade, you will hear a hum from the loudspeaker. Hold the screwdriver by its insulated handle, and note that instead of the hum, there is only a click when you touch pin 1. For this test most servicemen use one finger instead of a screwdriver. Try this, being sure to touch only pin 1. Incidentally, this is the first check to make on a dead receiver. If you hear a signal from this point, you know that the audio system is operating, and that the trouble is between the second detector and the antenna. If you do not hear a click or hum, you know the trouble is in the audio system or power supply, and you can proceed accordingly.

Now, short the oscillator tuned circuit to kill reception, and turn the volume control completely on. You can short the tuned circuit by putting a screwdriver blade between terminal C5 of the tuning capacitor and the chassis. Arrange the screwdriver so that it will be self-supporting. Touch terminal P3 of the volume control with your finger. A hum indicates that everything from this point to the loudspeaker is working. If you get a hum at the 12AT6 grid, but not at terminal P3, sometimes called the "hot" terminal, of the volume control, coupling capacitor C6 might be open. Technicians usually touch this volume control terminal rather than the grid of the first audio tube because the volume control is easier to find.

Step 3: To show the effectiveness of a circuit disturbance test in localizing a defect.

Unplug the receiver and disconnect the B+ end of the 12AT6 plate load resistor R7 from the circuit. This removes plate voltage from the 12AT6 tube. Plug in the receiver and touch pin 2 of the 50C5, and then pin 7 of the 12AT6. Each of these will produce a click. Next, touch pin 1 of the 12AT6 tube. You will hear nothing, showing that the trouble lies between this point and the plate of the 12AT6 tube. It could be due to lack of plate voltage, as happens to be the case, or to a control-grid-to-cathode short in the tube. It could also be due to loss of emission in the tube. A few checks with your tvom and trying a new tube would enable you to make a quick repair.

Step 4: To show how the input of the rf and i-f stages can be disturbed to produce a click in the loudspeaker.

With the receiver unplugged, resolder the B+ end of R7 to the proper point in the circuit, but leave the screwdriver shorting out the oscillator section of the tuning capacitor in place. Plug in the receiver and turn the volume control on completely. Hold another screwdriver blade or your longnose pliers in your hand, and touch the free end to control grid pin 1 of the 12BA6 tube. You will hear a click in the loudspeaker. Now touch the mixer grid, pin 7 of the 12BE6; you will again hear a click.

Step 5: To show that the circuit-disturbance test is effective in isolating trouble to an rf stage.

Unplug the receiver and unsolder cathode bias resistor R4 in the i-f amplifier stage from pin 7. Remove the screwdriver that is shorting the oscillator tank circuit, turn up the volume control all the way, and try tuning in a station. The set should be dead.

You can tell that the af system is working by touching the hot terminal of the volume control with your finger. Now touch the diode plate, pin 6, of the 12AT6 tube. You should get the same amount of hum, showing that the secondary of the i-f transformer is not open.

Now, touch the plate of the 12BA6, pin 5, with the screwdriver blade. Since your hand is touching the blade, be sure your body is not grounded and does not touch any part of the receiver. You should hear a click in the loudspeaker when you touch the plate, showing that signals are capable of passing from this point, through the second detector-audio amplifier, and to the loudspeaker.

Now touch the control grid, pin 1 of the 12BA6 tube. Compare what you hear (which will probably be a very faint click if anything at all) with the click you heard when R4 was in the circuit. The faint click that you may have heard was due to the disturbance signal feeding back through the avc and power supply line to the audio section. The signal, however, did not go through the 12BA6 tube.

Thus, to locate the defect, you would check the tube, the operating voltages, and the component parts in the i-f amplifier stage.

Resolder resistor R4 back to pin 7 before going on to the next step.

Step 6: To show that touching the oscillator grid will also result in a loudspeaker noise.

Tune to a point on the dial where a station is not received, and touch the oscillator grid, pin 1 of the 12BE6, with your finger or the screwdriver blade. Note the noise produced from the loudspeaker.

Discussion: The circuit disturbance test is very useful in working on a dead receiver, or on a set that is so weak it is practically dead. Sometimes, because of interaction between stages, the circuit disturbance test is not effective. You probably noticed this when you touched the grid of the i-f amplifier stage in Step 5. However, there are other techniques that can be used, which you will learn later.

In making the circuit disturbance test, bear in mind that in some places, especially in the rf and i-f stages, touching the grid of a tube with an insulated screwdriver will produce a click. In the first audio stages, your hand should be in contact with the screwdriver blade. In still others, where the gain is low between the point of disturbance and the loudspeaker, you may have to make a radical change in plate current. You did this when you shorted the control grid of the 50C5 to the cathode. Removing all bias in this manner causes a very large change in plate current with a resulting loud click from the speaker. As long as you do not leave the short in the circuit for any length of time, there is no chance of damaging good parts as a result of the short.

Instructions for Statement 62: Although the circuit disturbance test is very useful, it may not always tell you what you want to know. Here you will compare its effectiveness to the effectiveness of measuring the dc bias voltage of the oscillator in deciding if an oscillator is operating.

First, tune to a point where a station is not received, and turn the volume control up completely. Touch the oscillator grid, pin 1 of the 12BE6, with your finger or a screwdriver blade. Now measure the dc voltage between pin 1 and B−.

Next, short the oscillator tank with your screwdriver as you did previously. Recheck the dc voltage on pin 1, comparing it with that obtained when the oscillator was working. With the tank still shorted, touch pin 1 with your finger, and compare the loudspeaker noise to that heard when the oscillator was working. You now have sufficient data to complete the statement.

Statement No. 62: If the oscillator is suspected of being dead, a circuit disturbance test:

(1) is a satisfactory
[✓ *(2) is not a satisfactory*]

method of determining if the oscillator is working.

EXPERIMENT 63

Purpose: To show the effects of some common filament defects.

Introductory Discussion: In servicing an ac-dc receiver, you may find any one of three filament circuit defects. These are:

1. No tubes light.
2. Tubes light intermittently.
3. Some tubes light -- others are dark.

This experiment illustrates still another filament circuit defect. Before going on, however, let us discuss the three defects listed above.

In a normally operating ac-dc receiver, the tube filaments are in series, and the same current flows throughout the entire filament circuit. You would expect an open anywhere in the circuit to prevent all of the tube filaments from lighting. This is why many technicians are puzzled when they find an ac-dc set where some of the tubes light and some do not. At first it would appear that if any of the tubes light, they should all light; and that if one does not light, none should light. However, both types of defects can occur in the filament circuit of an ac-dc set.

Experimental Procedure: For the following steps you will need:

2 120 ohm resistors
tvom
receiver

Step 1: To check filament circuit continuity with the ohmmeter.

When you have an ac-dc set where none of the tubes light, you know that either the wall outlet is not delivering power or that there is an open in the series filament circuit consisting of the power cord, the On-Off switch, and the tube filaments as shown in Fig. 63-1.

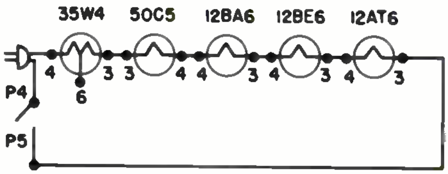

Fig. 63-1. Filament circuit of 7YY receiver.

The power outlet can be quickly checked, either directly or indirectly. A direct check is made either by plugging a piece of apparatus, such as a floor lamp, into the wall outlet and seeing if it lights, or by measuring the supply voltage. To check the voltage, you can push a thin-bladed screwdriver into either of the holes in the wall outlet and connect the ground clip of your tvom to the screwdriver blade. Push the probe into the other wall outlet hole, and measure the available voltage.

An indirect check of the outlet can be made by removing the receiver power plug from the wall outlet and connecting the ohmmeter across the prongs of the plug. Turn on the switch, and if you find continuity, you know that the filament circuit is not open. Therefore, the defect must be in the wall outlet. If you do not find continuity, you know the defect is in the receiver.

To see how to localize an open in the filament circuit, simulate an open by turning off the On-Off switch. Remove the power cord from the wall outlet, clip the ground lead to one prong of the plug, and touch the probe, using the R X 10 range, to pin 4 of the 35W4 tube. If you measure zero resistance, that side of the line cord is not open. If you get an open circuit reading, switch the ground clip to the other prong and repeat the measurement. If you get zero resistance, that side of the line cord is not open.

Now, leave the ground clip attached to the prong of the power cord where you measured zero resistance, and move the probe to pin 3 of the 35W4 tube. You will get a reading on the ohmmeter, indicating that there is continuity, and that the tube filament is not open. Now move the probe right around the circuit to pin 3 of the 50C5, 4 of the 50C5, 4 of the 12BA6, 3 of the 12BA6, 4 of the 12BE6, 3 of the 12BE6, 4 of the 12AT6, 3 of the 12AT6, terminal P5 of the On-Off switch, and finally to terminal P4 on the On-Off switch.

In each case, if you get a reading, you know there is continuity from the line plug to that point. You should get a reading each time, until you touch the probe to terminal P4 of the On-Off switch. This indicates that the tube filaments are not open, and you would suspect that the switch is defective. When checking continuity in this manner, remember that if you get a reading at one point but no reading at the next test point, you have located the circuit defect.

Instead of making point-to-point continuity measurements, you could remove the tubes and check their filaments individually with your ohmmeter. Try this on the 35W4 tube. Connect the clip of your tvom to pin 4, and touch the probe first to pin 6 and then to pin 3. In each case you should get a resistance reading.

This is the method to use if the receiver is in the cabinet so that you cannot get at the bottom of the tube sockets. Each tube should be checked individually. If all the tubes have continuity, then you know there is probably an open in the power cord or a defective On-Off switch. An open in the power cord is usually right at the power plug, and you can cut off the old plug and install another. Do not repair the power cord until you have checked the switch. You will have to remove the receiver from the cabinet to check it. These switches, however, seldom become defective.

Step 2: To check filament circuit continuity using ac voltage measurements.

You can check the filament circuit with your voltmeter instead of with the ohmmeter. The test procedure is almost the same.

To see how to do this, plug your receiver into the wall outlet, and remove the 12BE6 tube to simulate an open in its filament, and turn the set on. None of the tubes will light, since the filament circuit is open. Now connect the ground clip of your tvom to the power line side of the On-Off switch, terminal P4.

Set your tvom so that it will measure the full ac line voltage. Touch the probe to each of the filament pins of the tubes, working from the 12AT6 back toward the 35W4, as shown in Fig. 63-1. You will not get a reading when you touch pins 3 and 4 of the 12AT6 and pin 3 of the 12BE6 tube socket. When you touch pin 4 of the 12BE6 socket, you will measure the full line voltage. Since the circuit is open, normal current is not flowing through the tube filaments, and there is no voltage drop across them.

Reinsert the 12BE6 tube, and pull out the 50C5. Note that you do not get a reading as you work from the 12AT6 tube socket, until you again measure full line voltage when you touch pin 3 of the 50C5.

Turn the set off temporarily, and connect the ground clip of the tvom to pin 4 of the 50C5. Turn the set on, and touch the probe to pin 3. You will measure full line voltage just as you did when the clip was connected to the line. Now reinsert the 50C5 tube, and again touch the probe to pin 3. Note that in this case you measure approximately 50 volts, the normal filament voltage of the tube.

When you are looking for an open in the filament string, always remember to have the Range Selector switch set so that the tvom will measure full line voltage. If you have the Range switch set so that you can measure normal filament voltage, the meter will be overloaded when it is connected across the defective tube filament. Since this is a tvom the meter will not be damaged, but you should always get in the habit of using a range which will not cause the meter pointer to go off-scale.

Step 3: To show the effects of heater-cathode shorts.

To introduce a defect in which some tubes light and others are dark, temporarily connect a lead from pin 4 to the center post of the 12AT6 tube socket. This represents what would happen if a cathode-to-heater short developed in the 12AT6 tube.

Turn the receiver so that you can see the tubes, plug the power cord into the ac wall outlet, and turn the set on. All of the tube filaments will light except the 12AT6. This tube is dark. Remove the short between pin 4 and the center post of the 12AT6 socket.

You do not have to use test instruments when you find a condition of this type. Simply examine the schematic and consider what would happen if the cathode of any of the tubes shorted to its filament. The filament circuit beyond that point would be shorted out. In your 7YY receiver, if the short is in the 12AT6 tube, only that tube would not light, as you have just demonstrated. If you found that both the 12BE6 and the 12AT6 tubes were dark, you would suspect a cathode-to-heater short in the 12BE6 tube.

Step 4: To show the effects of a heater-cathode short in the audio output stage.

Take the two 120-ohm resistors and lay them side by side. Twist the adjacent leads together a turn or two to connect the two resistors in parallel. We will refer to the parallel 120-ohm resistors later as a 60 ohm resistor. Clip off one of the leads from each end of the resistor combination.

With the set unplugged, solder one end of the 60-ohm resistor to pin 1 of the 50C5. Solder the other lead to pin 4 of the same tube. Before you plug in the receiver, examine Fig. 63-1 and try to determine the results of your sabotage. Will all the filaments light? Will the set be dead? Plug the receiver in and observe its behavior. Check to see if all filaments light. Try to tune in a station. Turn off the receiver and remove the 60-ohm resistor from between pins 1 and 4.

Discussion: We have not attempted to show the effect of the third filament defect -- an intermittently open filament. The filament of a tube may become brittle with age and crack. When it is heated, the filament will expand, and the circuit will open. When the circuit opens, all of the tube filaments will go out. As the defective filament cools, it will contract, and the broken ends of the filaments will come back together, thus re-establishing current flow through the circuit. The time intervals between light and no light from the filaments are generally equal.

This defect cannot be located with an ohmmeter because when the tube filament is cold, there is continuity. Usually you cannot locate an intermittent open of this type with a tube tester. Very often the cathode will remain hot after the filament has opened, and will continue to emit electrons until the filaments have cooled sufficiently to come together again.

Trouble of this type, however, can be located with an ac voltmeter. You would use the same procedure given previously, by leaving the voltmeter connected in each test position long enough for the filament to open. If the voltage reading drops to zero, you know that the tube you are measuring across is not defective. However, if the voltage rises to the full line voltage, you have located the defective tube.

You can either make your measurements from one end of the filament string, or you can connect the meter directly across the filament of each tube, one at a time. Regardless of which method you use, the Range Selector switch of the meter should be set so that the full line voltage can be measured. Remember this test procedure. You will have occasion to use it in servicing TV sets as well as radios.

In each of the tests you have just conducted, the defect causing the receiver to be dead was indicated by the fact that some or all of the tubes failed to light. There are many other defects causing a set to be dead, which give no visible symptom. When you cannot see the underlying cause of a defect, you must use some servicing method that will quickly lead you to the defective section, stage, and part.

Instructions for Statement 63: In this experiment you have seen the effects of heater-cathode defects in some of the receiver circuits. For this statement you will observe the effects of a heater-cathode short in the i-f amplifier stage.

Solder one lead of the 60-ohm resistor to pin 4 of the 12BA6. Solder the other lead to pin 7 of the same tube. Turn on the receiver and observe the tube filament. Turn the volume control up and observe the results. Turn off the receiver, remove the 60-ohm resistor and answer the statement below and on your Report Sheet.

Statement No. 63: When I simulated a heater-cathode short in the i-f amplifier stage, I found

(1) all filaments
[✓ *(2) the 12 volt filaments*]
(3) no filaments

were dark and the 60 Hz hum

[✓ *(1) was louder*]
(2) was weaker
(3) did not change

as I advanced the volume control.

EXPERIMENT 64

Purpose: To show the effect of low emission in an amplifier tube and to show methods of quickly locating the defective tube.

Introductory Discussion: When we say that a tube has low emission, we mean that the cathode does not give off as many electrons as normal. We can demonstrate this by reducing the filament current to the point where the cathode is insufficiently heated to emit a normal quantity of electrons. We will do so in this experiment by partially shorting the filament of the 12AT6 with a resistor. This will lower the filament voltage of the 12AT6 from about 12 volts to approximately 4 volts ac. The extra voltage will be divided among the other tube filaments, but the increase of each will be too small to cause excessive filament current.

Shunting the tube filament also illustrates another defect frequently found in receivers. In some cases an internal short develops in a tube filament; and in an ac-dc filament string, the effect is exactly the same as that of an external resistor across a filament.

For this experiment you need your receiver, in first-class working condition, your tvom, and:

1 120-ohm resistor
1 60-ohm resistor

Step 1: To measure the plate voltage and the filament voltage of the 12AT6 tube.

Turn your set on, and when it warms up and is operating, measure the voltage between B- and the plate, pin 7 of the 12AT6 tube, and the filament voltage (B- to pin 4) of the same tube. Record your readings in Fig. 64-1.

CIRCUIT CONDITION	PLATE VOLTAGE	FILAMENT VOLTAGE
NORMAL	50VDC	12AC
FILAMENT PARTIALLY SHORTED	80VDC	3AC

Fig. 64-1. Record your readings for Exp. 64 here.

Next, feel the envelope of the 12AT6 tube so you can judge its temperature. Do not grasp the tube too tightly or you may burn your fingers. Now turn the set off and let it stand for five or ten minutes while the tubes cool.

Step 2: To measure the plate and filament voltages with the filament partially shorted.

Connect a 120-ohm resistor in parallel with the two already connected in parallel and connect the resulting 40-ohm resistor between pins 3 and 4 of the 12AT6 tube socket. Do not connect the third 120-ohm resistor permanently to the resistor combination since you will use it in a later experiment.

Turn the set on, and let it warm up for about five minutes. With the reduced filament voltage, it will take quite some time for sufficient heat to reach the cathode to produce any electron emission. Touch your finger to the grid of the 12AT6 from time to time so you can see how long it takes for the cathode of the tube to warm up.

When touching pin 1 of the 12AT6 tube causes a slight buzz in the speaker, try tuning in stations with the volume control all the way up. If you are near any stations and your line voltage is normal (115 volts or more), you will be able to pick up programs, but they will be quite weak.

Now repeat the plate and filament voltage measurements you made in Step 1. Record your readings in Fig. 64-1. Then, feel the tube envelope; notice how the heat produced compares to that when normal filament voltage is applied.

Discussion: You will frequently get sets for repair that take a long time to warm up. In some cases, the volume will be almost normal when the receiver does warm up. In others, the volume will remain quite weak.

In ac-dc receivers, you should suspect that one of the tubes has a partially shorted filament. A defective electrolytic capacitor will also cause the set to take a long time to warm up. Any tube can have a partially shorted filament, but it is more common in higher voltage tubes, such as rectifiers and power output tubes.

It is a good idea to be careful when you touch any of the tubes in a receiver. You may be badly burned if you grasp a tube firmly without first finding out how hot it is. Therefore, just barely touch the tube. If you find that it is not very hot, then you can grasp it more firmly.

Insufficient heat can be caused by a partially shorted filament, as in this case, or a lack of cathode emission. A partially shorted filament reduces the power dissipation in the filament, which is the greatest heat source in the tube.

You will seldom find this trouble in an ac-operated set. If a partial short does occur, the current through the rest of the filament will rise to the point where the filament will burn out, and the tube filament will be completely open. In ac-dc receivers, partial filament shorts are fairly common.

A partially shorted filament cannot be found with a tube tester, because in a tube tester, normal filament voltage is applied to the filament regardless of its condition. Thus, the tube will test good. However, you can test a tube suspected of having a partially shorted filament by measuring the ac filament voltage or by substituting another tube.

If you find that the filament voltage of a tube in a heater string is lower than normal, you can be pretty certain that the tube has a partially shorted filament, and you should install another tube.

The variations in the dc operating voltages that you recorded in Fig. 64-1 were due to the plate current variations of the tube. When the plate current is extremely low, there is little voltage drop across the plate load resistor. Therefore, the plate voltage has almost the same value as the B supply voltage. When the tube is drawing normal plate current, there is a large drop across the plate load resistor, and the plate voltage is lower. Remember that when there is a high value plate-load resistor in the circuit, excessively high plate voltage indicates lower-than-normal plate current.

Instructions for Statement 64: Remove the 40 ohm resistor from across the filament of the 12AT6 tube, and put it across the filament (pins 3 and 4) of the 12BE6 tube. You will not be able to pick up any stations when you try to tune them in. Check all operating voltages on the 12BE6 tube, and compare your results with those you recorded in Fig. 23. Think about the significance of the dc voltages you measure and complete the statement. Then, remove the resistors from pins 3 and 4 of the 12BE6 tube socket.

Statement No. 64: The receiver is dead when the 12BE6 tube has low emission because:

(1) the plate and screen voltages are too high.

[✓ *(2)*] *the oscillator is dead.*

(3) no rf signal voltage is being applied to the input of the stage.

EXPERIMENT 65

Purpose: To show the effect of leaky bypass capacitors in the B supply circuit;

and how to locate them with an ohmmeter and with a voltmeter.

Introductory Discussion: Leakage in a capacitor results when the dielectric resistance decreases to the point where dc can readily flow through the capacitor. To make a circuit act as though a bypass capacitor in it has become leaky, we can connect a resistor across the capacitor. We can simulate any degree of leakage merely by using resistors of various sizes.

To avoid damaging the rectifier tube, we will limit the leakage in each case to 3000 ohms. In an actually defective capacitor, the leakage could be higher or lower but 3000 ohms will show what can be expected and how the capacitor can be located with standard test procedures. We will simulate leakage in the plate bypass capacitor in the output stage, where leakage is frequently found, and in the rf bypass capacitor. The rf bypass capacitor in the plate and screen supply circuit of ac-dc sets does not become leaky as often as the one in the plate circuit of the output stage, but in TV receivers and in ac-operated radio sets where the B+ supply is higher, they often fail.

Experimental Procedure: For this experiment you will need the receiver in good operating condition, your tvom, and:

1 3k-ohm resistor

Step 1: To show the effect of leakage in the output tube plate bypass capacitor.

Solder one end of the 3k-ohm resistor to the plate, socket pin 7, of the 50C5 tube, and the other end of the resistor to terminal DB1.

CAUTION: With this resistor in the circuit, do not leave the receiver turned on too long, because abnormally high current will flow through the resistor and overheat it. For short periods of time, long enough to make the necessary measurements, it will be safe to have the set turned on. As soon as you have finished making a measurement or observation, turn the set off.

Turn the receiver on, allow it to heat up, and tune in a station. You may be able to note that the sensitivity is somewhat lower than normal. Turn the set off, and prepare your tvom for positive dc voltage measurements. Set the Range switch in the 120-volt position, and clip the ground lead of the tvom to a B− point. Turn on the receiver, allow it to heat up, and measure the dc voltage on screen pin 6 of the 50C5, and plate pin 7 of the 50C5. Record the values in Fig. 65-1, and turn off the receiver. Now compare these voltages to those you recorded in Fig. 23.

MEASUREMENT FROM B− TO	STEP 1 VOLTAGE	STEP 2 RESISTANCE
CATHODE OF 35W4 (PIN 7)		4K
SCREEN GRID OF 50C5 (PIN 6)	53v	4.5K
PLATE OF 50C5 (PIN 7)	84	3.4K

Fig. 65-1. Record your voltage and resistance measurements here when the plate bypass capacitor is leaky.

Step 2: To show how leakage in the plate bypass capacitor of the output tube affects the dc resistance measurements.

Disconnect the set from the power line. Leave the ground lead of the tvom connected to B- Discharge the filter capacitors by shorting the cathode of the rectifier to B- with a screwdriver blade or a piece of hookup wire. Now measure the resistance from B- to the cathode of the 35W4, to the screen of the 50C5, and to the plate of 50C5. Record the values in Fig. 65-1. Compare your readings with the normal readings to B- in Fig. 24.

Disconnect the 3k-ohm resistor from the plate of the 50C5 (pin 7) and from B-.

Step 3: To show the effect on dc operating voltages if the rf bypass capacitor C9 is leaky.

Connect the 3k-ohm resistor from the screen (pin 6) of the 50C5 tube to B-. Turn the set on, let it warm up, and tune in a station. You may be able to notice that the sensitivity is again somewhat lower than normal. Next, perform the voltage measurements indicated in Fig. 65-2. Record the values.

Study these readings, comparing them with the ones for Step 1 and with the normal readings in Fig. 23. See if they will tell you anything about the probable location of the leaky part.

MEASUREMENT FROM B–TO	STEP 3 VOLTAGE	STEP 4 RESISTANCE
CATHODE OF 35W4 (PIN 7)		4,5K
SCREEN GRID OF 50C5 (PIN 6)	73VDC	3.5K
PLATE OF 50C5 PIN 7)	84VDC	4,6K

Fig. 65-2. Readings for Steps 3 and 4.

Step 4: To show the effect of leakage in the rf bypass capacitor on resistance measurements.

Unplug the receiver from the power line, and measure the resistance from the cathode of the 35W4 to B-. If the meter pointer reads off-scale, discharge the electrolytic filter capacitors by shorting the cathode of the 35W4 to B- with a piece of hookup wire.

Now measure the resistance from the screen of the 50C5 to B- and the resistance from the plate of the 50C5 to B-. Record your readings in Fig. 65-2. Study the values carefully, comparing them with those in Step 2, and also with the normal readings in Fig. 24. See if you can deduce from these measurements the probable location of the trouble.

Discussion: When either of the two shorts you introduced was in place, the receiver played with only slightly reduced sensitivity. If either of the capacitors had actually been leaky, the condition would have become progressively worse, and, eventually, the receiver would have gone dead. Perhaps the filament tap on the 35W4 would have opened. However, the method to use in localizing trouble of this kind through measurements is the same, regardless of the degree of leakage.

When looking for a defect of this kind, small variations from the normal voltage values are very important. In Step 1 all the readings should be lower than normal. The important thing to notice is that the reading at the screen of the 50C5 is considerably below normal and that the reading at the plate of the 50C5 changed even more. You will be able to see the variations more clearly if you will subtract the voltage values you recorded in

Fig. 65-1 from those recorded in Fig. 23. Enter them in the margin opposite the values in Fig. 65-1.

Even if it were only 1 or 2 volts, the fact that the plate voltage decreased more than the screen voltage is sufficient to indicate that the short is probably on the plate side of the output transformer primary rather than on the screen side. Then, if you studied the schematic diagram of the set carefully, you would see that leakage in the plate bypass capacitor of the tube would cause these particular readings, and you would disconnect the capacitor to check it. You could check the capacitor with an ohmmeter; or you could simply disconnect it and repeat the voltage measurements. If you measure normal voltages with the capacitor out of the circuit, you know that the capacitor is leaky.

In Step 2 the resistance between the plate of the 50C5 and B- should be the lowest. The resistance from the screen of the 50C5 to B- should be slightly higher, again showing that the leakage is on the plate side of the tube rather than on the screen side.

The fact that the resistance from the cathode of the 35W4 to B- is higher than from the plate of the 50C5 to B- indicates that the short is not on the cathode side of the output transformer but somewhere on the plate side or in a part connected to the plate side. The diagram shows that there is a plate bypass capacitor, so you would check it first.

In Step 3 again all of the voltages decreased, but this time the greatest decrease is in the screen voltage. Again subtract the values in Fig. 65-1 from the normal values in Fig. 23, and enter them in the page margin. The larger screen voltage variation indicates that the excess leakage is somewhere in the B+ line.

By examining the schematic diagram, you can see that the trouble could be due to leakage in C9 or C11B, or that there could be a partial short in one of the tubes or from any terminal in this circuit to B-. The voltage measurements show the approximate location of the trouble, but do not point to any particular part. You will have to check the parts you suspect are causing the trouble until you locate the defect.

When looking for a defect of this type, do not go through the receiver and check and replace parts indiscriminately. After you have located the defective stage or circuit, refer to the schematic diagram and determine what part would cause that type of defect. This is the procedure used by all successful radio-TV technicians.

In Step 4, the resistance measurements show that the lowest resistance is from the screen of the 50C5 to B-. This indicates that the trouble would not be in plate bypass C8 or in the input filter capacitor. It is somewhere in the regular B+ line.

Both the voltage and resistance measurements point to the defective circuit, but do not show which part in the circuit is defective.

Looking at the diagram, you would see that leakage in either C9 or C11B could cause the trouble, so you would disconnect the capacitors one at a time, and check them either by measuring the circuit voltage without the capacitor or by making resistance measurements on the capacitor itself. In most cases you would quickly find the defective part.

Instructions for Statement 65: In some receivers, you will find a small rf plate bypass capacitor between the plate and the cathode of the first audio amplifier stage. The capacitor is not needed in the plate circuit of the 12AT6 tube in this receiver because the circuit consisting of C5 and R5 acts as an i-f filter. These components prevent practically all the i-f signal from reaching the control grid of the 12AT6 tube.

For this statement, let us suppose that the 12AT6 uses such a capacitor, and that it has developed a leakage path with a resistance of 3000 ohms. To simulate this, connect your 3k-ohm resistor between pin 7 of the 12AT6 tube and terminal DB1.

For the statement of this experiment, you are to determine which of the three troubleshooting methods--voltage measurements, resistance measurements, or circuit disturbance tests -- is the quickest and easiest method to use in localizing the defect to a particular section of the receiver.

Turn the set on, allow it to warm up, and try to tune in a station. You will find that the receiver is dead. Measure the B- to cathode voltage of the rectifier, the B- to screen voltage of the output tube and the B- to plate voltage of the output tube. Then, measure the B- to plate voltage of the 12AT6 tube. Compare the values with those you recorded in Fig. 23.

Turn the set off, and measure the resistance from B- to cathode, of the 35W4, B- to screen to the 50C5, B- to plate of the 50C5, and B- to plate of the 12AT6 tube. Compare these measurements with the normal measurements in Fig. 24.

Finally, turn on the receiver, and momentarily short the grid and cathode pins 1 and 2 of the 50C5 tube with a screwdriver. Next, momentarily touch the plate of the 12AT6 tube with the screwdriver, and notice whether there is a buzz or click from the loudspeaker. Then, touch the grid, pin 1, of the 12AT6 and again listen for the buzz or click.

Consider the symptoms you would be called upon to repair, and decide which method is the quickest and easiest to use in localizing the defect. Then answer the statement. Remove the 3k-ohm resistor.

Statement No. 65: With a leaky plate bypass capacitor in the 12AT6 circuit, I found that the quickest way to localize the trouble to this stage was by:

(1) voltage measurements.
(2) resistance measurements.
[✓ *(3) a circuit-disturbance test.*]

EXPERIMENT 66

Purpose: To demonstrate typical causes of hum in a receiver; and to show how the hum can be localized to one section and to one stage of the receiver.

Introductory Discussion: When a technician finds hum in a set, he usually looks for its cause in the power supply, because the filter system in the power supply is supposed to remove hum (ripple) and deliver pure dc to the tube electrodes. The filter capacitors are the most frequently defective.

In this experiment you will learn about filter capacitor defects, and about other causes of hum. Some of these are not common, but finding them can be very time-consuming. You will learn how to localize hum to one section and to one stage.

Experimental Procedure: To carry out this experiment, you need your receiver, your tvom, and the following parts:

1 20-μf, 150-volt capacitor
1 3k-ohm resistor
1 220-ohm resistor
1 0.25 μf or 0.27 μf capacitor

Step 1: To demonstrate the effects of high power factor in the input filter capacitor.

Turn the volume control down to the no-sound level. Then, use your ac voltmeter to measure the ac ripple voltage between B– and each of the following points: the 35W4 cathode, the 50C5 screen grid, and the 50C5 plate. Record the readings in Fig. 66-1.

To simulate a high power factor in the input filter capacitor, unplug the receiver and unsolder the lead of the electrolytic capacitor going to terminal DB2. Connect the 3k-ohm resistor in series with this lead and terminal DB2.

Turn on the set, and allow it to warm up. Note that there is a hum coming from the loudspeaker.

Now, measure the ac ripple voltage at the cathode of the rectifier and at the plate and screen grid of the output tube, and record the readings in Fig. 66-1. Compare these with the normal readings.

Try tuning in various stations to judge the performance of the set. You will find the performance is somewhat different from normal. Now check the defective capacitor just as a technician would by shunting the 20 μf, 150-volt electrolytic from the 35W4 cathode to B–. When installing an electrolytic in a circuit, you must observe its polarity markings. If you connect the capacitor with the wrong polarity, it will be ruined. Use the same polarity as for the original capacitor.

Solder the negative lead of the test capacitor to B–. Now, with the set on and a station tuned in, touch the positive lead of the test capacitor to terminal DB2. The hum should drop to almost its normal level at the same time the volume comes up. You may not be able to detect the increase in volume since the hum effectively masks the change in volume, so you will use your tvom to measure it. Set the tvom to measure ac volts on the 120-volt range. Tune to a station that is broadcasting speech and measure the ac voltage from pin 7 of the 50C5 to B–. Adjust the volume so that the average speech level will produce a variation of about two divisions (4 volts) on the meter scale. With the tvom still connected to

AC RIPPLE FROM B– TO	NORMAL	HIGH POWER FACTOR IN C11A	HIGH POWER FACTOR IN C11B	SHORT BETWEEN + LEADS OF FILTER CAPACITORS
CATHODE OF 35W4	5	34	4.7	3.2
SCREEN GRID OF 50C5	.35	2.6	2.8	3.3
PLATE OF 50C5	3	25	7.4	6.7

Fig. 66-1. Record your readings for Exp. 66 here.

the plate of the 50C5, touch the positive lead of the test capacitor to terminal DB2. Now note the average variations indicated on your tvom. Even though they are at a lower average level, the variations should be considerably larger than before, indicating an increase in volume.

Next, check the dc voltage at pin 7 of the 35W4 with and without the test capacitor in place. Note the radical drop in dc voltage caused by an input filter capacitor that is open or has developed a high power factor. (The two troubles are practically the same as far as a serviceman is concerned because they give similar results.) From this we can conclude that a high power factor in the input filter capacitor causes weak reception as well as hum. In a set using a filter choke rather than a filter resistor, less hum will be heard and at the same time there will be a smaller drop in dc supply voltage. Thus, the complaint would probably still be weak reception as well as hum.

Step 2: To show the effect of a high power factor in the output filter capacitor.

Remove the 3k-ohm resistor from the input filter capacitor circuit and resolder the positive lead of the input capacitor to terminal DB2. Next, unsolder the positive lead of the output filter capacitor from terminal DB3 and solder one free lead of the 3k-ohm resistor to the capacitor lead you just disconnected. Solder the other end of the 3k-ohm resistor to terminal DB3. The output filter will now act as if it has developed a high power factor or has become open. An open means that the capacitor lead is broken inside the case and does not make contact with the foil used as the plate.

Now turn on the set, and with the volume control adjusted for no sound, listen to the hum from the loudspeaker. You will find that there is a considerable hum present, indicating that an open or high power factor in the output filter capacitor produces considerable hum. If the loudspeaker were in its cabinet, the hum level would be even higher than it is.

Now, measure the ripple voltage at the rectifier cathode, at the screen, and at the plate of the 50C5. Record your readings in Fig. 66-1. Compare these to those you measured for a defective input filter capacitor.

Measure the dc voltage at the rectifier cathode and at the screen and the plate of the 50C5. Compare them with the values you recorded in Fig. 23. You will find that the high power factor in the output filter capacitor has little or no effect on the dc voltages. For this reason you would not expect any great change in volume.

Now with the receiver turned on and the volume turned all the way down, shunt the output filter capacitor with your 20 μf test capacitor. The negative lead of the test capacitor should still be connected to B-. Connect the positive lead to terminal DB3. This connects the test capacitor across the original output filter capacitor and the 3k-ohm resistor. The capacitor must shunt both of them because the 3k-ohm resistor represents the resistance inside the case of a defective capacitor.

Notice how the hum level drops as soon as you connect the test capacitor across the defective part. This is the method used by technicians to test a capacitor for high power factor or an open. Remember, however, that a capacitor must be disconnected from the circuit to test it for leakage.

Step 3: To show the effect of a short between the positive leads of filter capacitors in a common container.

Restore the receiver to its original condition by removing the 3k-ohm resistor from the circuit, and resoldering the positive lead of the output filter capacitor to terminal DB3. Try the set out to make sure it is working normally and that the hum is back to its normal level.

To show what happens when a direct short occurs between the positive leads of the filter capacitors, solder a piece of hookup wire from terminal DB2 to terminal DB3. Turn on the set, and notice the hum. Measure the ripple voltage at the rectifier cathode and at the plate and screen of the 50C5. Record the values in Fig. 66-1. Notice that the ripple voltage at the screen of the 50C5 is the same as that at the cathode of the 35W4. This indicates that there is no voltage drop across the filter resistor.

Now, try to reduce the hum by alternately shunting the input and output capacitors with your test capacitor. Be sure to observe the polarity of the test capacitor. You will find that shunting the test capacitor across either the input or the output capacitor has little effect on the hum level. This is a pretty good indication that there is a short or leakage between the positive leads of the filter capacitors. When you suspect this defect, there is only one thing to do. Completely unsolder the original capacitors from the circuit and install others. If this clears up the trouble, you know there is a short between the positive leads of the original capacitors.

The capacitor sections may not be completely shorted as they are here. To simulate a partial short, remove the piece of hookup wire, and solder one lead of a 220-ohm resistor to terminal DB3. Position the other lead so that it can be pushed into contact with terminal DB2. Turn on the set and move the free lead of the 220-ohm resistor into contact with terminal DB2 using a screwdriver or pencil. Notice the hum level increases with the partial "short" in place.

Remove the 220-ohm resistor. Then, check the receiver to be sure it is working properly before going on with the next step.

Step 4: To illustrate the effects of inter-element leakage, and to show how the stage at which the hum enters can be localized.

Leakage in a tube is not necessarily between the cathode and heater, although this is the most common type of leakage. There may be leakage between a diode plate and the filament. To see the effect of this, connect a 220-ohm resistor between pins 4 and 6 of the 12AT6 tube. This simulates a diode-plate-to-filament short.

Turn on the set, and allow it to warm up. Then advance the volume control. The hum level should increase as the control is advanced.

Since you can use the potentiometer to control the hum level, you know that the hum is originating on the input side of the volume control. With the control turned all the way down, the grid of the 12AT6 is essentially at B- potential as far as signals are concerned. As the control is gradually advanced, hum is fed to the grid of the tube and is amplified by the entire audio amplifier.

Advance the control to a point where you can hear the hum clearly. Then, take your 0.27 μf capacitor and touch one lead to B-, and touch the other to the control grid of the 12AT6. Note that the hum drops to zero, indicating that it was getting into the grid circuit of the tube. Now, touch the free lead of the 0.27 μf capacitor to plate pin 5 of the 12BA6 tube. There will be no change in hum, indicating that the hum is not originating in the 12BA6.

Now touch the free lead of the capacitor to the plate pin 7 of the 12AT6 tube. Again the hum will drop to a low level. These tests are pretty definite proof that the trouble originates in the 12AT6 tube or in its input circuit. You would try a new tube in such a case. Remove the 220-ohm resistor.

Step 5: To show the effect of hum modulation.

Hum modulation is hum that is heard only when an rf carrier is tuned in. To demonstrate this effect, disconnect the antenna lead at terminal C4 of the strip on the rear of the tuning capacitor. Hold the bare end of the free lead in your hand. Turn the receiver on, and allow it to warm up. Advance the volume control to a point where you can tune in stations. You will notice that as each station is tuned in, you will hear hum, and the sound may be distorted. In some cases, the sound may be clear, but it will still be accompanied by hum. If no hum is heard, reverse the power plug connected to the power outlet. This is sometimes due to cathode-to-heater leakage in an rf tube, and is sometimes due to signals picked up through the house wiring and modulated (because of a poor connection in the house wiring) by the 60 Hz current. If these signals get into the receiver, the 60 Hz modulation will be demodulated along with the radio signal, and will be heard in the loudspeaker. It is for this reason that the 0.01 μf bypass capacitor, C10, is included across the power line at the input to the receiver. Any signals attempting to enter by way of the power line are bypassed by this capacitor.

Now resolder the antenna connection to terminal C4 and make sure that the receiver is operating properly.

Discussion: Open loop antennas can cause trouble, and may block reception entirely, making the receiver dead. They may also cause chopped-up or intermittent reception, or may produce a form of hum. If you suspect an open in the loop antenna, check for continuity between the loop terminals. In receivers where the loop is attached to the cabinet, the defect is usually in the connecting leads.

Hum in either ac or ac-dc receivers is generally due to defective electrolytic capacitors, or to cathode-to-heater leakage in one of the tubes. In servicing, therefore, check these possibilities first -- shunt the capacitors one at a time with good ones, and check the tubes in a tube tester or by substitution.

You also demonstrated the effect of leakage between sections of the electrolytic capacitor. This frequently happens through the capacitor case, and very often occurs under the capacitor mounting strap. If you suspect this, push the capacitor so that the part under the strap is exposed. If there are green corroded spots, there is leakage to the strap and the capacitor should be replaced. Sometimes just moving the position of the strap will clear up the trouble, but there is usually enough leakage through the cardboard casing of the capacitor to prevent normal operation.

Instructions for Statement 66: In shunting the electrolytic capacitors with your test capacitor, you probably noticed a large arc between the capacitor lead and the 35W4 cathode as the uncharged capacitor charged. Ordinarily this does not cause trouble, but in some receivers sufficient current may be drawn from the rectifier to burn out the rectifier filament. This is particularly true in some of the older three-way portable receivers.

To avoid the surge of current into the uncharged capacitor, you can precharge the capacitor before connecting it across the input of the filter. To demonstrate this, turn the set on, and let it warm up. The 20 μf capacitor should still be connected to B-. Therefore, short the leads of your test capacitor, and then connect it to the cathode of the rectifier.

Now discharge the test capacitor, and connect it from B- to the screen of the output tube. You will see an arc as the capacitor charges, but the 1k filter resistor limits the charging current to a safe value. Now, without discharging the capacitor, shift its positive lead from the screen of the 50C5 to the cathode of the rectifier and note the arc. You now have sufficient information to answer the statement. Remove the capacitor from the circuit.

Statement No. 66: I found that if the capacitor connected across the input filter has previously been charged, the current flowing into the capacitor when contact is made to the rectifier cathode is:

(1) more than
[✓ *(2) less than*]
(3) about the same as

when an uncharged capacitor is used.

EXPERIMENT 67

Purpose: To show common causes of oscillation and how to locate them.

Introductory Discussion: Oscillation can be due to defective parts, to misplaced wiring, or to poorly soldered connections. If a part is defective, the trouble is usually easy to find.

Oscillation is the result of energy being fed back from the output of a stage to its input. This is called single-stage oscillation because only one stage in the receiver is involved. Overall oscillation occurs when the feedback path involves two or more stages. For example, from the plate of the 50C5 to the input of the 12AT6.

Oscillation can occur in either the af section or in the rf section. If turning the volume control down stops the oscillation, look for trouble in the af system. If tuning the receiver affects the oscillation, look for trouble in the rf section.

Oscillation does not always follow a fixed pattern. The defect that causes oscillation in one set may cause only regeneration or have no apparent effect in another. Regeneration is feedback in insufficient quantity to cause the receiver to squeal. Oscillation may result in a squeal, or it may cause motorboating. The position of the leads, the gain of the particular tubes used, and the Q of the tuned circuits determine the exact effects. These cannot always be predicted.

If your particular receiver is exceptionally stable, you may not get the results described. If not, go on to the next step, but remember the description of the effects so you will recognize them when you are doing servicing.

Experimental Procedure: To conduct the following steps, besides the receiver and your tvom, you will need:

- 1 0.25 μf or 0.27 μf capacitor
- 1 20 μf, 150-volt capacitor
- 1 120-ohm resistor
- 1 100k-ohm resistor
- 1 3k-ohm resistor

Step 1: To show that an open plate bypass capacitor for the power output tube and misplaced wiring may result in overall oscillation.

First, check your receiver to be sure it is operating normally. Now disconnect C8 from terminal DB1. Tune to a station, and turn the volume control up. If you hear a rushing, high-pitched squeal, the 50C5 has gone into oscillation. However, there may be no effect, especially if the grid and plate leads are well separated and are kept close to the chassis.

To give the effect of misplaced wiring, cut a piece of hookup wire about 9 inches long, and remove some of the insulation from one end of the wire only. Solder this lead to plate socket terminal 7 of the 50C5 tube. Bend the wire around until the insulation is against the grid lead of the 12AT6.

Now turn on the set again, and advance the volume control setting. You should hear a very loud squeal at a certain volume level. This indicates that energy is being fed back from the plate circuit of the 50C5 to the grid circuit of the 12AT6, resulting in overall oscillation. While the receiver is squealing, push the case of C8 so that the lead you disconnected is in good electrical contact with terminal DB1. This should stop or, at least, reduce the oscillation.

When replacing output transformers, be sure to keep the leads short and down close to the chassis. This will prevent radiation from the plate lead which might induce signal voltages in the input of the output tube or in the input of the first audio tube.

Turn the set off, unsolder the piece of hookup wire from the plate of the 50C5, and solder C8 firmly in place. Now try out the receiver to make sure that it is still operating normally.

Step 2: To show that the screen grid shields the plate from the control grid.

In this step you will install an unbypassed resistor in the screen supply of the i-f tube. In most ac-dc receivers the screen connects directly to B+, but in TV sets and in ac-operated receivers there is usually a resistor used to reduce the screen voltage, and a bypass capacitor between the screen and the chassis. If the bypass capacitor opens, oscillation will occur.

To demonstrate this, unsolder the three leads going to pin 6 of the 12BA6. Twist the three bare leads together and connect a 3k-ohm resistor between pin 6 of the 12BA6 tube socket and the junction of the three leads. Position these parts so nothing shorts out. Now turn on the receiver, and try tuning in stations. You will hear squeals as stations are tuned in. A signal voltage is developed across the screen supply resistor, and because of the capacity between the screen grid and the control grid, feedback takes place within the tube.

While the receiver is oscillating, touch one lead of a 0.27 μf capacitor to a B- point, and the other lead directly to the screen of the 12BA6 tube. Note that the oscillation stops. This is the method used by technicians to check suspected capacitors.

Now permit the receiver to oscillate, and bring your hand near the oscillator coil. Note that, as your hand approaches this coil, the pitch of the oscillation changes because you are changing the oscillator frequency by changing the capacity in the oscillator circuit. Exactly the same effect is produced by adjusting the tuning capacitor knob of the set. Many technicians are fooled by this effect; they assume that there is a defect in the oscillator circuit, when the trouble is really elsewhere in the receiver.

Step 3: To show that under some conditions a high power factor in the output filter capacitor results in overall oscillation.

Turn the set off, and remove the 3k-ohm resistor. Solder the three leads back to pin 6 of the 12BA6. Possibly you may be unable to get the three wires back through the hole in pin 6. In that case simply "tack" solder the three leads to pin 6. If the solder is allowed to flow smoothly over the joint, a good mechanical connection will result. Now try out the receiver to be sure that it is operating normally.

In the preceding experiment, you demonstrated that high power factor in the output filter capacitor produced hum. However, a small increase in power factor will not have any appreciable effect on the hum level. To demonstrate this, disconnect the positive lead of the output filter capacitor, C11B, from terminal DB3 and connect a 120-ohm resistor in series with this lead.

Turn the set on. If you notice any increase in hum, it will be very slight. However, there is another effect that would be noticeable if it were not for the 0.1 μf rf bypass capacitor. To demonstrate this, turn the set off, and disconnect this capacitor from the screen grid, pin 6, of the 50C5. Turn the set back on, turn up the volume, and tune over the dial. You will probably hear squeals and howls wherever a station should be received, because the electrolytic capacitor will not bypass rf signals, and signal voltage is built up in the B supply and is fed from one stage to another, resulting in oscillation.

To prove that the trouble is in the electrolytic, shunt your test electrolytic, the 20 μf capacitor, from DB3 to B- with the proper polarity. If you have trouble holding the leads in contact with the proper points in the circuit, turn the set off, solder the capacitor in place, and then turn the set back on to recheck it. You should get normal operation.

Now disconnect the test electrolytic, and let the receiver oscillate. Move the lead of the 0.1 μf rf plate bypass capacitor so that it is again in contact with the screen of the 50C5. As soon as you make contact, the oscillation will stop.

As an electrolytic capacitor ages, its ability to serve as an rf bypass decreases, and oscillation takes place. A paper bypass capacitor, even one as small as 0.01 μf, is used in parallel with the electrolytic output filter capacitor in well designed receivers to prevent this trouble. The set may play for months or years before the power factor in the electrolytic increases to the point where hum becomes a problem.

Remove the 120-ohm resistor from the circuit, and resolder the positive lead of the output filter capacitor to terminal DB3, and the 0.1 μf bypass to the screen of the 50C5 tube. Try out the set to be sure it is working normally.

Step 4: To show that single-stage rf oscillation can be due to misplaced wiring.

Solder a short length of wire to the control grid, pin 1 of the 12BA6. Gently push the wire down near the blue i-f transformer lead connecting to the plate of the 12BA6. Turn the set on, and after it warms up, try tuning in stations. You will find violent oscillation. If you do not get this oscillation, try moving the lead around and bring it even closer to the plate lead of the 12BA6. Do not, however, permit the end of the wire to come in contact with any parts or with the chassis.

The squeal may not be as loud as some of those you have formerly noticed, because the tremendous avc voltage being developed practically blocks all signals from the mixer. Check on this avc voltage by connecting the ground clip of the tvom to Pl of the volume control and touching the probe to the hot side of the volume control P3. The Function switch should be set to measure a negative dc voltage. You will measure from 3 to 15 volts across the volume control. Notice that this voltage does not vary as you tune the receiver throughout the tuning range. This avc voltage is being applied to the control grid of the mixer and also to the 12BA6 tube.

In a receiver, of course, you would not look for a piece of stray hookup wire hanging on the control grid of an i-f amplifier. However, the same effect would be produced if either of the i-f transformers had been replaced and the leads had not been cut to the proper lengths and kept close to the chassis. Therefore, when replacing i-f transformers, remember to keep the wiring neat and as much like the original as possible.

When you are satisfied that you have made the necessary observations in this experiment, turn the set off, and leave the lead connected to the control grid of the 12BA6. You will use it in the statement at the end of this experiment.

Discussion: In ac-dc receivers, oscillation can be caused by open bypass capacitors, defective output filter capacitors, and misplaced wiring.

In some cases, misalignment results in oscillation. Frequently, if a receiver is dead because of a defective oscillator, an inexperienced person may start adjusting the i-f transformers. He may turn them out far enough so that the i-f amplifier is actually tuned to a station at the low-frequency end of the broadcast band. Then the tuned circuit in the plate circuit of the mixer may be sufficiently near the tuned circuit in the grid circuit to permit feedback at the same frequency, resulting in oscillation. Therefore, in servicing a receiver, do not adjust the i-f transformers unless you have a good reason to.

In some receivers, oscillation will not occur when an i-f amplifier is peaked exactly. A slight detuning, however, may cause oscillation, because when one winding of an i-f transformer is detuned, the secondary winding absorbs less power from the primary, and the primary impedance rises. The voltage across the primary also rises, and stray coupling in the circuit may permit enough feedback into the grid circuit to cause oscillation.

Single-stage rf-if oscillation can often be controlled by increasing the bias. In your receiver, the cathode bias resistor for the i-f tube is 150 ohms. If there were uncontrollable oscillation, which could not otherwise be stopped, you could install a larger value resistor. Sometimes a resistor value will have to be as high as 300 or 400 ohms.

In your receiver, you have grounded the center shield on the rf-if tube sockets. If the ground (B-) connection were left off, feedback could occur between the plate and control grid, resulting in oscillation. This is a point you should watch in servicing receivers. The center shields in these stages should be grounded.

In servicing a set for oscillation, you should carefully examine the top of the chassis to see if all the tube shields are in place. Leaving off a tube shield frequently results in oscillation. The tubes requiring shields can be easily identified; their bases will have metal rings into which the shields should go.

Octal-base tubes were used in older ac-dc sets, and in many ac sets. These tubes may be either glass or metal. If oscillation is the complaint, try metal tubes in the rf-if stages. If you do this, ground pin 1, unless it is used as a tie point for other purposes. The No. 1 pins connect to the metal shell, which acts as a shield around the tube.

In older receivers using a three-gang tuning capacitor, check the wiper contacts used to ground the rotors to the capacitor frame. A dirty contact or a high resistance at this point will result in feedback between the sections, and oscillation in the rf stage. You will rarely find this difficulty in ac-dc sets, because practically no ac-dc receivers use a tuned rf stage.

Instructions for Statement 67: For this statement you will learn another method frequently used to eliminate oscillation. Turn your set on, and with your finger, move the short lead connected to the 12BA6 control grid away from the plate to the point where oscillation starts. In other words, if you move the lead farther, there will be no oscillation. With the receiver oscillating, turn off the set.

We will now proceed to lower the Q of the resonant circuit feeding the control grid of the 12BA6 and note the effect on the oscillation. Solder one end of your 100k-ohm resistor to the the control grid of the tube, and the other end to the avc line at terminal KB3. Do this without disturbing the position of the free lead connected to the control grid of the 12BA6. Now turn on the set, and try tuning in stations over the dial. You should now be able to answer the statement. Remove the 100k-ohm resistor and the short piece of wire from the circuit.

Statement No. 67: With the first i-f transformer secondary loaded by a 100k-ohm resistor, I found that the oscillation:

(1) increased.
[✓ *(2) decreased.*]
(3) remained the same.

EXPERIMENT 68

Purpose: To show that distortion can be caused by a leaky coupling capacitor in an RC coupled amplifier stage, and if so, there will be a dc voltage drop across the grid resistor of the following stage.

Introductory Discussion: Up to the final audio stage, we are primarily interested in obtaining as high a voltage gain as possible without undesirable feedback, oscillation, or distortion. In the final stage, however, we must develop sufficient power to drive the loudspeaker. This is done by using power pentodes or beam power output tubes. Typical examples are the 3V4, 3S4, and 3Q5 tubes used in older battery sets, the 6BQ5, 6BK5, 6V6, and 6AQ5 tubes used in ac-operated sets using a power transformer, and the type 50C5, 35C5, and 50L6 tubes used in ac-dc sets.

All type 50C5 beam power amplifier tubes have rather high harmonic distortion when operated in single-ended (one tube) output stages at high audio output levels. To keep the distortion to a minimum, it is common to operate these tubes as class A amplifiers. This means that the bias for such a tube must be sufficient to keep it operating on the straight part of its Eg-Ip characteristic curve, and the input signal must be limited so that it will never drive the grid positive, and thus produce a grid current flow.

RC coupling is generally used between the plate of the voltage amplifier stage and the grid of the power output stage. The coupling capacitor is likely to have high voltage peaks applied to it. Thus, in some receivers, the capacitor is likely to become quite hot. It is not uncommon, therefore, for it to become leaky, or to break down completely after being in service for some time. When this happens, the plate voltage, which is positive with respect to ground, is applied to the control grid of the following stage, causing a large grid current to flow. If the grid current flow is allowed to continue for any great length of time, it will permanently damage the tube. The effect of such a breakdown on the operation will be severe distortion, because the stage is no longer operating as a class A amplifier. In this experiment you will demonstrate the effects of leakage in the coupling capacitor.

Experimental Procedure: Here you need the receiver and your tvom, plus:

1 1 meg resistor

Step 1: To simulate leakage in the coupling capacitor.

Solder one lead of the 1 meg resistor to the control grid, pin 2, of the 50C5 tube socket, and arrange the other lead so that it can be pushed into contact with plate pin 7 of the 12AT6 socket.

Step 2: To demonstrate the effects of a leaky coupling capacitor.

Turn on the set, tune in a station (preferably one presenting a musical program), set the volume at a fairly high level, and then push the 1 meg resistor into contact with plate pin 7 of the 12AT6 socket. Use the eraser end of a pencil, or a small wooden stick for this. The reproduction should be weak and distorted.

Tune to other stations, and repeat the foregoing procedure. Distortion should be produced in all instances.

To avoid damaging the 50C5 power output tube, release the 1 meg resistor from contact with plate pin 7 as soon as you have noted the effect of the simulated leakage.

Step 3: Measure the dc voltage across the 470k-ohm grid resistor R8, first with coupling capacitor C7 normal, then with leakage simulated.

Prepare your tvom for dc voltage measurements, and turn on the set. Tune in any local station, and adjust the volume to a comfortable level. Now see if you can measure a dc voltage across the 470k-ohm grid resistor. Enter the value for each test in Fig. 68-1. If you get no reading, write 0 in the space.

Without turning off the set or changing the position of the Function switch, set the Range switch at 12V, and push the free lead of the 1 meg resistor into contact with plate pin 7 of the 12AT6 tube socket. There should now be an appreciable dc voltage indicated by your meter. Enter the value you get in Fig. 68-1. Turn off the set, and disconnect the tvom. Also unsolder the 1 meg resistor from pin 2 of the 50C5 socket.

CONDITION OF C7	READING
NORMAL	0
LEAKY	12V

Fig. 68-1. Record your readings for Exp. 68 here.

Discussion: Since the 50C5 power output stage of your receiver is supposed to operate as a class A amplifier, you should get no voltage for either of the measurements when no leakage is simulated in the coupling capacitor C7. A -dc voltage reading could occur only if the tube were drawing grid current, which would happen only if there were no bias. However, you may get a small positive reading because there may be a slight amount of gas in the 50C5. If this is true, the voltage will remain when you disconnect C7.

When you simulate leakage by connecting the 1 meg resistor across C7, you should get an appreciable voltage. The leakage resistance you are using, together with grid resistor R8, constitutes a voltage divider for which the plate voltage of the first audio stage acts as a source. This voltage divides across the leakage resistance of the coupling capacitor and the grid resistor according to their values, and with such polarity that the grid of the output tube is now positive. This causes a flow of grid current and a tremendous increase in the plate current, and severe distortion takes place in the output.

Whenever you have a case of severe distortion in general service work, check for a positive dc voltage across the grid resistor of the power output tube. If there is voltage, and the set uses a power transformer for the filament supply, pull out the power output tube and again check for voltage across the grid resistor. If there is none now, the output tube is gassy and should be replaced. However, if the voltage does not disappear when the output tube is removed, the coupling capacitor is leaky, and should be replaced.

In ac-dc sets, the tube filaments are in series, so you cannot pull out the output tube. Here, you must disconnect the coupling capacitor and repeat your measurement. If the voltage disappears with the capacitor disconnected, you know the capacitor is leaky; otherwise, the tube is gassy.

Another defect you will find in your work as a technician is an open grid resistor in the first audio stage. You will simulate this defect in order to answer the statement for this experiment.

Instructions for Statement 68: It is not uncommon to find the grid resistor of the 12AT6 tube either open or increased greatly in value. You will determine the behavior of the receiver with an open grid resistor in the first audio stage.

Tune in a station and adjust the volume to a comfortable level. Unplug the receiver and unsolder the lead of the 10 meg resistor connected to pin 1 of the 12AT6. Leave the set turned off for about five minutes to allow the tubes to cool off. Then turn the set on and observe the sound as you turn the volume control up and down. Continue listening to the sound for about five minutes then answer the statement below and on your Report Sheet.

Statement No. 68: I found that, with an open resistor in the grid of the 12AT6, the audio output at first distorted:

(1) at low volume
[✓ *(2) at high volume*]
(3) at all volume

control settings and, after a short time, the sound

[✓ *(1) improved.*]
(2) disappeared.
(3) faded to a very low level.

Reconnect the lead of the 10 meg resistor to pin 1 of the 12AT6 and check to make sure the receiver is operating properly.

EXPERIMENT 69

Purpose: To show that noise can be localized by a stage-blocking technique, even though blocking is so incomplete that some noise can still be heard.

Introductory Discussion: The circuit disturbance test that you demonstrated in a previous experiment is based on the fact that any sudden irregular current change will produce a noise in the loudspeaker. In a circuit disturbance test, these current changes are deliberately produced for the purpose of localizing the source of trouble when a receiver is dead.

There are many things that will create the sudden current changes that produce noise in the output of a receiver. These may be within the set itself, such as poor contact in a volume control or a partial or intermittent open in an rf or af transformer, or external to the set, such as arcing electric motor brushes and defective neon signs. In this experiment, you will deal only with noise that originates within the set itself.

After creating a source of noise, you will demonstrate the stage-blocking technique in which you will make each stage in turn inoperative, and note if the noise is still present in the output. In an ac-operated set, this can be done by pulling out the tubes one by one. Since you cannot pull out the tubes in ac-dc receivers, technicians generally short-circuit the input and output of each stage in turn. This is the method you will follow in this experiment.

Experimental Procedure: For this experiment you will need:

1 20 μf electrolytic capacitor

Step 1: To create an intermittent open in the plate circuit of the 12BE6 converter stage.

Unsolder the blue i-f transformer lead from pin 5 of the 12BE6 tube socket. Remove all solder from the hole in this pin, and any excess solder that may be on the end of the blue wire.

Now, push the blue lead back into the hole, and if possible, place it so that striking the chassis or table forcibly with your hand will produce an intermittent contact between the plate lead and the pin. Turn on the set and try this effect. If you find it difficult to get the correct adjustment of this lead, the noise pulses can be produced by striking the loose lead with the eraser end of a pencil.

Step 2: To block the input to the mixer-oscillator stage.

Solder the negative lead of the 20 μf capacitor to the ground terminal in the center of the 12BA6 socket. Turn on the receiver, set the volume control for a high output, create noise pulses by striking the chassis or by moving the loose plate lead, and note that noise is plainly audible in the loudspeaker. Touch the positive lead of your blocking capacitor to pin 7 of the 12BE6 tube to block the input to the mixer oscillator stage. Continue creating noise pulses and note they are still plainly audible in the output. It is not necessary for the receiver to be tuned to a station for these tests.

Step 3: To block the input of the 12BA6 i-f amplifier stage.

Move the positive lead of your blocking capacitor to pin 1 of the 12BA6 and create the noise pulses. Note that although the noise is still audible, it is not nearly so loud.

Step 4: To block the output of the i-f amplifier stage.

Move the positive lead of the blocking capacitor to pin 5 of the 12BA6. Create the noise, and again note that although it is still audible, it is not nearly as loud.

Remove the stage block long enough to tune in a station. Then restore the block at pin 5, and again create the noise pulses. Although the incoming program is blocked, the noise pulses should still be audible in the speaker. This proves that the noise pulses are not getting into the output along the usual signal paths.

Now restore the receiver to normal operation. Securely solder the loose plate lead to pin 5 of the 12BE6 tube socket.

Discussion: As you found in Step 2, a stage block between the input of the set and the source of the noise will have no effect on the strength of the noise pulses in the output, because the normal signal path from the noise source to the loudspeaker is unobstructed.

However, the reason that the noise is still audible when the signal path is blocked anywhere between the noise source and the output is not so apparent. To understand this, you must remember that the noise is caused by a sudden current change. In this experiment, it is the plate current of the 12BE6 mixer-oscillator stage that is changing and producing the noise in the output. Since this changes the loading on the power supply unit, small changes occur in the plate and screen currents of other stages. This again produces noise; but since these changes are very small compared to the change that produces them, these noise pulses are comparatively weak.

You must also consider the fact that every time the contact at the plate pin of the tube socket is made and broken, a small electric arc is formed. This arc produces a pulse of rf energy, which can be picked up by unblocked rf stages by direct radiation from the arc, or the rf energy may travel along the intercircuit wiring to unblocked stages.

You may begin your stage-blocking procedure at either the input or the output of the set. In either case, the defective stage is indicated by a change in the noise level as you move the block along. Thus, in the experiment, you started at the input and worked toward the output. Noise was heard at the original loudness level until the defective stage was passed, then the noise level was much weaker. If you had started at the output stage and worked toward the input, the noise pulses would have been weak until you passed over the defect, then the noise pulses would have become much stronger.

Instructions for Statement 69: For your report on this experiment, you will simulate noise originating in the audio section of the set, block the following stage, and determine whether or not the results are the same as those observed in carrying out the experiment. Proceed as follows:

Solder a short piece of hookup wire to pin 7 of the 12AT6. Position the wire so you may easily touch it to terminal DB3. Turn on the set and make and break the contact between DB3 and the hookup wire. This should produce noise in the output.

Try a block ahead of the trouble by touching the positive lead of the blocking capacitor to pin 1 of the 12AT6. Again make and break the contact between pin 7 and terminal DB3 and note the effect on the noise.

Now block the output of the 50C5 by touching the positive lead of the blocking capacitor to pin 7 of the 50C5. If the capacitor leads do not reach this far conveniently, resolder the negative lead to a more convenient ground connection such as terminal DB1. Turn on the set and again create noise pulses. Note the effects, then answer the statement below and on the Report Sheet.

Restore the receiver to normal operation by removing the short wire and the blocking capacitor.

Statement No. 69: When I blocked the output stage, noise pulses, which were created by opening and closing the plate circuit of the first audio stage:

(1) could still be heard
[✓ *(2) could not be heard*]

from the loudspeaker.

EXPERIMENT 70

Purpose: To show alignment problems; and to show how alignment can affect tracking.

Introductory Discussion: The i-f, rf, and mixer stages of the superheterodyne receiver are aligned to produce maximum signal strength at the second detector output for each station tuned in, so that the dial pointer indicates the frequencies of the various stations accurately.

Misalignment can have several effects. The local oscillator frequency may not be separated from the frequency of the rf tuned circuit by the i-f frequency over the entire tuning range, although stations will come in at about the right dial settings. In this case we say that the oscillator and preselector do not track. Another effect of misalignment might be that the oscillator and preselector track, but the dial readings are not correct at the lower frequencies.

To carry out this experiment successfully, you must be able to receive strong stations at both ends of the dial. You should have a station you can easily identify that operates between 1400 kHz and 1600 kHz, and one that operates between 550 kHz and 900 kHz. Preferably the station frequency should fall on a marked division of the dial, especially at the high-frequency end. At NRI we used stations at 1500 kHz and 630 kHz.

If you do not receive such stations in your locality, do only the first part of Step 1 and the Statement. Do not detune the i-f's.

Your results will depend on the ease with which you can spot stations on the dial, the condition of your receiver to start with, and the care with which you follow the instructions.

You will find it much easier to tune in the stations accurately if you use the rim of the tuning knob rather than the smaller center knob. In this way, you can tune in stations more easily.

A properly aligned i-f amplifier is the heart of the superheterodyne receiver. If the i-f amplifier is properly aligned, the oscillator and preselector trimmers can easily be adjusted using known broadcast station signals.

Experimental Procedure: You need only your receiver and the tvom.

To guarantee consistent results, it is important to set the antenna winding on the ferrite rod exactly in the center of the rod. Later, you may find you can peak up the low end of the band by slightly repositioning the winding.

Step 1: To check the tracking of the oscillator, preselector, and dial.

You have already made preliminary adjustments of the oscillator and preselector trimmers. You will now check the alignment of your receiver at the high end of the band.

Tune to a station at the high end of the band and make sure the dial setting is correct for this station. If the receiver has been jarred or banged while performing the experiments, the oscillator adjustment may be slightly off and the high frequency station may be at the wrong dial setting. If it is, turn the dial to the correct setting and adjust the oscillator trimmer CT2 to bring in the station. CT2 is the trimmer farthest from the front panel. Now adjust the preselector trimmer, CT1, for maximum volume.

With the receiver still tuned to the high frequency station, carefully adjust the i-f slugs for maximum volume beginning with T2. Make these adjustments very carefully since the slugs will need only very slight adjustment. Do the same thing with the adjustments on T1.

You will adjust your i-f transformers with the alignment tool provided. So that you can easily observe how far you have turned the tool, attach a piece of tape to the center of the alignment tool as shown in Fig. 70-1. The end nearest the tape "flag" is the end to use for all transformer adjustments. It is possible to adjust both the top and bottom slugs of the transformer from either the top or bottom hole. However, to avoid confusion, you should make all of your adjustments from the end closest to the

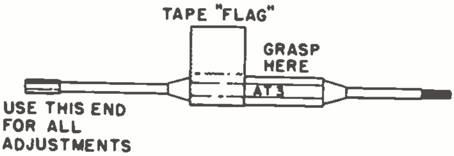

Fig. 70-1. Attaching a tape "flag" to the alignment tool.

slug that you are adjusting. Make sure that you insert the tip of the alignment tool into the transformer only far enough to reach the first slug.

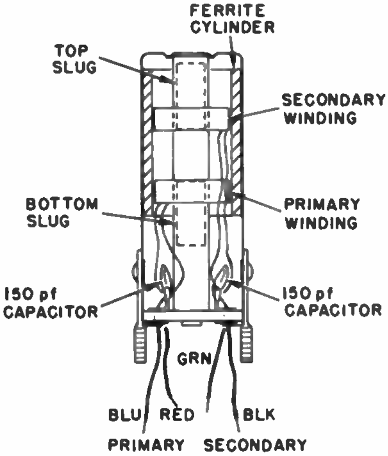

Fig. 70-2. Internal construction of the i-f transformers.

As you can see from Fig. 70-2, there is one powdered iron slug associated with each of the transformer coils. When you look at the transformer from the top, turning the top slug counterclockwise will move it toward the top of the transformer, and since the slug is moving away from the coil, the inductance of the coil will be decreased, so the resonant frequency will increase. Looking at the transformer from the bottom, turning the bottom slug counterclockwise will move it toward the bottom of the transformer, which will reduce the inductance of the bottom coil, and therefore raise the resonant frequency of that part of the transformer.

Next, detune the i-f's approximately 10 kHz by turning each of the i-f slugs one-eighth of a turn in a counterclockwise direction. This will raise the i-f about 10 kHz.

Instead of relying on your ear to indicate maximum volume while aligning the receiver, you will use your tvom to measure the avc voltage developed in the receiver. Clip the ground lead of your tvom to P1 of the volume control and the probe to P3. Set the meter to read -dc volts on the 3V range.

With the receiver still tuned to the highest frequency station and while watching the meter, adjust the rf trimmer CT1 on the front section of the tuning capacitor gang for maximum avc. Tune the receiver over the dial, noting how the avc reading increases as you tune to each moderately strong station. Weak stations will produce little avc.

Tune to the low-frequency end of the dial, and check the preselector and oscillator tracking by turning the dial knob to bring in a station for greatest avc. Do not touch the oscillator trimmer. Try adjusting the rf trimmer CT1 to see if the avc can be increased. If the receiver is tracking properly, no change, or less than half a turn of the trimmer should be necessary to pass through a maximum on the meter.

You will find that you have to tighten the rf trimmer almost all the way to get maximum avc and maximum volume. Leave the rf trimmer set for maximum volume, and tune back to the high-frequency station. Note how little avc is now produced. Readjust the rf trimmer for maximum avc. Naturally, something must be done, because the customer cannot readjust the rf trimmer each time he tunes in a new station.

Step 2: To show that poor tracking of the oscillator, preselector, and dial can be

due to incorrect alignment of the i-f amplifier.

You should have noticed that although the high-frequency station comes in at the correct dial setting, the low-frequency station comes in at a somewhat higher dial setting than called for by its operating frequency. The condition is not serious and would probably go unnoticed unless your attention were called to it. The receiver is not tracking its dial as well as it might, because the i-f amplifier is tuned to approximately 456 kHz, but the i-f frequency that should be used with the oscillator coil and dial is about 446 kHz.

Normally a serviceman would read the i-f value on the manufacturer's diagram and would realign the i-f amplifier to the specified frequency using a signal generator. If you have a signal generator, you can use it to check the i-f alignment after completing Experiment 70.

Now tune to the low-frequency station, and set the dial slightly below the point where maximum avc is received, but where the station can still be heard. Adjust the first i-f transformer, T1, and then the second i-f transformer, T2, for maximum avc. The slugs will have to be turned only a very small amount so make the adjustment carefully.

Again set the dial pointer toward the low-frequency end at a point where you can still hear the station. Readjust the first and second i-f transformer slugs for maximum avc. Repeat this procedure once more (three adjustments in all), remembering to reset the dial to a lower frequency and to adjust the first i-f transformer and then the second i-f transformer.

This procedure should lower the frequency of the i-f amplifier about 10 kHz, and the low-frequency station should be coming in at very nearly its right dial setting, or perhaps a little lower.

Now tune to the correct dial setting for the high-frequency station, and adjust the oscillator and rf trimmers, CT2 and CT1, for maximum avc. You may find that the trimmers do not need to be readjusted. Tune to the low-frequency station, and check the tracking by adjusting the rf trimmer. If it is already peaked and no further (not more than half a turn) adjustment is needed, the oscillator and preselector are tracking each other and the dial. If you still have to screw the trimmer rather tight, the i-f is still too high, and the procedure of lowering the i-f should be done once more. Don't go too far or the i-f will be too low. If you experience any difficulty in making these adjustments or if you do not get the proper tracking as described, return the i-f trimmers to the settings used in the beginning of this experiment.

Discussion: You probably wonder why readjustment of the i-f amplifier frequency three times changes the i-f by 10 kHz. The receiver has a band width of slightly less than 10 kHz; you can tune away from a desired station about 3-1/3 kHz, and still receive its signal. If you shift the frequency 3-1/3 kHz three times, and readjust the i-f each time, there will be an overall change of approximately 10 kHz in the i-f amplifier frequency.

Exact tracking between the rf and oscillator is possible, but is seldom achieved in commercial receivers. Usually some slight readjustment of the rf trimmer can be made to improve the tracking at a given frequency. If the necessary readjustment is small, the change in volume cannot be noticed by the ear.

Some manufacturers compromise on the adjustment by setting the oscillator at the highest dial marking, for example 1600 kHz, and adjusting the rf trimmer at 1400 kHz so that the tracking is equally good at the high and low ends of the dial.

Remember that in a well designed receiver using specially cut plates in the oscillator section of the tuning capacitor, poor tracking is an almost sure sign of incorrect i-f alignment. If you have to screw the rf trimmer in at the low-frequency end, the i-f is too high; if you have to loosen the rf trimmer at the low-frequency end, the i-f is too low. To lower the i-f, tune below a station, and readjust the i-f slugs. To raise the i-f, tune the receiver above a station, and readjust the i-f slugs. In both cases the job is easier if you use a station at the low-frequency end of the dial. A signal generator set to the particular value recommended by the manufacturer can be used to adjust the i-f, or you can use the methods outlined in this experiment.

Many different i-f values have been used in commercial receivers. Frequencies of 130 kHz, 175 kHz, 262 kHz, 455 kHz, 456 kHz, and 470 kHz have been commonly used in broadcast receivers. Other values can, of course, be used; for example, we used 446 kHz for this receiver.

Instructions for Statement 70: Strip 1/4" of insulation from both leads at one end of a 3" length of twisted wire. Make sure the insulated ends are not touching one another by slightly separating the two leads. You will use this length of twisted wire as a small capacitor of about 5 pf to slightly detune the rf input and the two i-f transformers.

Turn on the receiver and tune in a station at the low end of the band (550 kHz to 700 kHz). Clip the ground lead of your tvom to terminal P1 on the volume control and the probe to P3. Set the tvom to read -dc volts and note the avc voltage.

Turn off the receiver and solder one lead of the twisted pair to the center post of the 12BE6 tube. Solder the other lead to pin 7 of the same tube. Turn on the receiver and adjust the tuning knob for maximum avc voltage. Note the value of voltage. 6 → 8

Turn off the receiver and disconnect the leads from pin 7 and the center post of the 12BE6. Reconnect the leads to pins 5 and 6 of the 12BE6. Now the capacitor is across the primary of the input i-f transformer. Turn on the receiver and adjust the tuning knob for maximum avc voltage. Note the value of voltage. 6 → 7

Turn off the receiver and disconnect the leads from pins 5 and 6. Reconnect the leads to pin 6 and the center post of the 12AT6 tube. The capacitor is now across the secondary of the output i-f transformer. Turn on the receiver and adjust the tuning knob for maximum avc voltage. Note the voltage. You now have enough information to answer the statement. Turn off the receiver and disconnect the two leads from the 12AT6 tube. ~~6 →~~ 3 → 5

Answer the statement below and on your Report Sheet.

Statement No. 70: I found the sensitivity of the receiver, as indicated by the avc voltage, was decreased most by detuning of the

[✓ *(1) first i-f transformer.*]
(2) second i-f transformer.
(3) preselector.

ALIGNING THE I-F WITH A SIGNAL GENERATOR

Here are some instructions on aligning the i-f amplifier section of the receiver, using a signal generator. If the rf signal from the generator is modulated by an audio signal, you can make your alignment adjustments by ear, adjusting the various slugs for maximum sound output. You can also use your tvom, connected across the volume control, to indicate when the transformers are peaked for maximum voltage output. Using a tvom will usually give better results; but if the input level is kept to a low value, your ear is quite sensitive to changes in volume.

The signal generator can be coupled to the receiver by connecting it between terminals C2 and C3 of the loop antenna. This will cause energy to flow through the second winding of the loop, and will induce the signal in the loop antenna. For i-f alignment, the receiver should be tuned to the low-frequency end of the dial, at a point where a squeal or a station is not received. If you cannot find such a point, you can stop the local oscillator by holding a screwdriver blade between the tuning capacitor plates to short it out. Adjust the i-f slugs to give maximum output at the setting of the signal generator. The signal generator should, of course, be tuned to the recommended i-f value (in this case, 446 kHz).

If a receiver has been badly misaligned, it is sometimes impossible to feed enough energy into the loop to get a reading on the output meter or to hear the signal. In this case, align the i-f transformers one at a time. Clip the ground lead of the signal generator to B- (clipping it to the chassis may result in hum modulation), and touch the hot lead of the signal generator to the control grid of the i-f tube. Adjust the second i-f transformer for maximum output.

You can then move the hot probe of the signal generator to the mixer grid of the detector-oscillator tube, and adjust the first i-f slugs. The exact order in which the slugs are adjusted is of no particular importance.

Clip the antenna and ground leads of the signal generator to the antenna and ground leads of the loop. The signal generator and the receiver should both be tuned to some setting at the high-frequency end of the dial such as 1600 kHz. If you do not receive a signal, adjust the oscillator trimmer for maximum signal. Next, tune the signal generator and receiver to a lower frequency, such as 1400 kHz, and adjust the rf trimmer for maximum output. Now tune to a station at the low-frequency end of the dial and see if adjustment of the rf trimmer improves the volume. If there is no noticeable improvement, the receiver is tracking properly.

CONCLUSION

This concludes the experiments in this kit. Check over your Report Sheet to see that you have answered all the Statements, and that your answers are just as you want them. Then send it to us for grading.

INSTALLING THE RECEIVER IN THE CHASSIS

Remove the power cord from both the receiver and the ac outlet. Slip one of the power cord clamps on the interlock connector as shown in Fig. 25. . . . . ( )

Fig. 25. Placement of first cord clamp on interlock.

Run the ac plug from the inside of the cabinet through the rectangular cutout marked "interlock." . . . . ( )

Draw the interlock portion of the cord into the cutout and push the second power cord clamp between the body of the interlock connector and the outside of the cabinet, as shown at "1" in Fig. 26. . . . . ( )

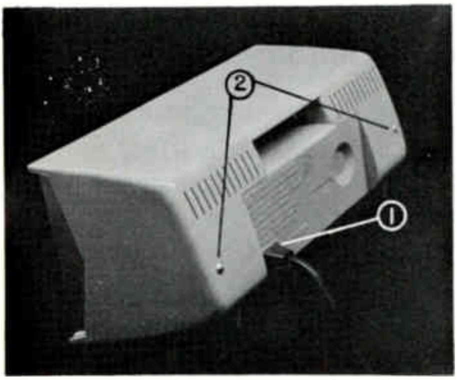

Fig. 26. Mounting the receiver in its cabinet.

With the cabinet right side up, position the chassis and panel so the chassis rests on the guide strips on either side of the cabinet. . . . . ( )

Slowly slide the chassis into the cabinet. Position the interlock connector so the interlock plug on the chassis will go into the female connector in the back of the cabinet. . . . . ( )

To make certain the interlock is correctly seated, plug in the receiver and turn it on. The receiver should operate. ( )

If it does not operate, pull the chassis forward and reseat the interlock connector. . . . . ( )

Place the two 4-1/4" screws through the two holes in the rear of the cabinet, as shown at "2" in Fig. 26. Tighten securely. . . . . ( )

The handsome 5-tube ac-dc superheterodyne receiver that you assembled in this kit is well worth keeping. You can use it on your servicing bench as a test set or use it in your home.

HELP YOUR MEMORY

Experience is a great teacher, providing you have a good memory! An unusual defect may take hours to locate the first time you meet it – but the next time, you should be able to spot the difficulty quickly. However, that "next time" may not occur for several months; by then you may have forgotten what you did.

You can aid your memory by keeping notes. Every time you meet an unusual trouble, write up a careful and complete description of its symptoms and your isolation procedure.

Also, draw schematics of any changes you may make in wiring. Even simple changes will make the circuit different from its original diagram and may give you puzzling test results at some later date, unless you are aware of the change.

After collecting this information, you'll never use it unless it is placed conveniently near your workbench. It is best to arrange your notes and sketches by make and model number in a file. In time, you will have a valuable assortment of service information – such as only YOU can collect!

John F. Rider

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ACHIEVEMENT THROUGH ELECTRONICS

nri

DC CIRCUIT CALCULATIONS

X105

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DC CIRCUIT CALCULATIONS

REFERENCE TEXT X105

STUDY SCHEDULE

☐ 1. **Introduction** . . . . **Pages 1 - 3**
Mathematics as a useful "tool" both in studying and working in the electronics field is discussed in this section.

☐ 2. **Arithmetic Review** . . . . **Pages 3 - 11**
Here is a review of arithmetic through the operations of addition, subtraction, multiplication, and division. You also learn the rules of order in this section.

☐ 3. **Fractions** . . . . **Pages 12 - 32**
Adding, subtracting, multiplying and dividing fractions are covered. There is also a section on mixed numbers and improper fractions.

☐ 4. **Decimals** . . . . **Pages 33 - 42**
In this section the operations of adding, subtracting, multiplying and dividing decimals are discussed. You also study how to multiply and divide by ten and how to do percentage.

☐ 5. **Solving Circuit Problems** . . . . **Pages 42 - 46**
You apply the facts you learned in this lesson to solve some simple dc circuit problems.

☐ 6. **Answers to Self-Test Quesions** . . . . **Pages 46 - 56**

☐ 7. **Answer the Lesson Questions.**

☐ 8. **Start Studying the Next Lesson.**

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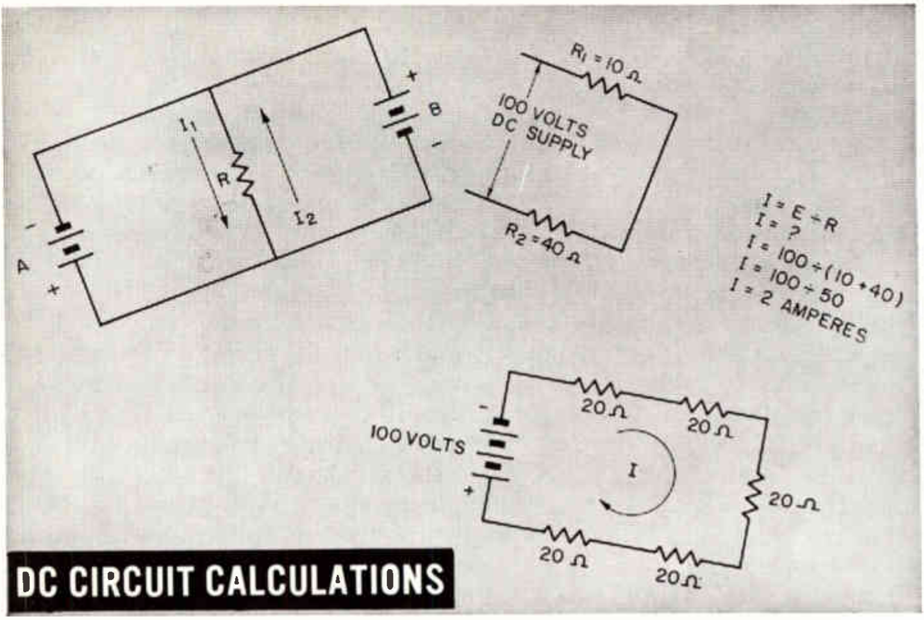
DC CIRCUIT CALCULATIONS



One of the very first things that is explained to anyone learning electronics is Ohm's Law. You will remember that this is the basic law covering the relations of voltage, current, and resistance in electrical circuits. In addition to being one of the most basic of the fundamentals of electronics, it is also one of the most important rules or laws. You will find that no matter how far you go in the study of industrial electronics, radio communications, or electronics engineering, this law which states that "the current flowing in a circuit is equal to the applied voltage divided by the resistance" will be used and applied over and over again.

At the same time that you learned about Ohm's Law, you also learned that it could be expressed much more simply by using the symbols for current, voltage, and resistance in the formula: I = E ÷ R. This is the mathematical expression of the law using symbols instead of words and is called a formula. Most of the rules or laws of electronics, or of any other science for that matter, are expressed with formulas for two reasons. One reason is that these simple mathematical expressions of the laws are much easier to memorize. The other reason is that they automatically provide a workable relationship of the laws for use in calculations. Thus, once you have learned the formulas, you not only have learned the rules, but you also have them expressed properly for use in circuit calculations.

One of the best things about formulas is that they can be arranged to find a particular quantity that we want to know. For example, the formula for Ohm's Law, I = E ÷ R, is used when we know the voltage and resistance and want to find the current in a circuit. We also learned that another way of saying the same thing is to state that E = I × R. We usually simplify this expression still further by dropping the × sign and writing the formula simply $E = IR$. This way of expressing the basic formula is used when we know the current and resistance and want to find the voltage.

By still another arrangement, we can state the formula so we can easily find the resistance by saying $R = E \div I$. We use the formula in this form when we know the voltage and current in the circuit and want to find the resistance. All three of these statements of Ohm's Law say exactly the same thing. They are simply arranged in different ways for convenience in making circuit calculations.

If you do not already know the three forms of Ohm's Law, stop right now and memorize them. You will save yourself a great deal of time in the long run, and in addition, knowing these formulas and understanding the way in which voltage, current, and resistance in a circuit are related will help you to understand electronic circuits. The three forms of Ohm's Law are:

$$I = E \div R$$
$$E = IR$$
$$R = E \div I$$

Actually the three forms of Ohm's Law are really only one formula with the letters manipulated around the equals sign. We are able to change these formulas around to suit our purposes by applying some very basic rules of mathematics. In electronics, we must learn quite a few formulas to perform certain calculations so that we can understand how the circuits work and what may be wrong with them. Of course, the formulas can be arranged depending on what we want to find out and what we already know. Obviously, if we have to learn not only all the formulas but all the different forms of the formulas as well, we would have to do a lot of memorizing.

This would be impractical because we can easily learn a few of the basic laws of mathematics and then change the formulas to suit our own purposes. By doing this, we need to learn only one form of each formula, plus the rules for changes. In this way, mathematics becomes a useful tool, both in studying, and working in the electronics field. You will learn how to rearrange formulas later, so that then all you will have to do is remember one form of Ohm's Law and you will be able to get the other two. Right now, however, to save time, be sure that you know all three forms.

These lessons in mathematics may be just review for you. However, don't skip over them lightly. They are just as important as any other lessons in your course. You must study them carefully and send in answers to the questions in the back of the book. The only difference between these mathematic lessons and your regular study lessons is the order in which you will do them. The math lessons should be studied immediately after the regular lesson text with the same number. For example, the first lesson should be studied after you finish lesson five.

We will break up our study of mathematics in this way for two reasons. The first and most important reason is that these math lessons are different from any you have ever seen. Most math textbooks teach general mathematics so that the learning can be applied to any subject. Here, we are primarily interested in mathematics from the standpoint of usefulness in electronics. In other words, we are interested in its application to a specific purpose. Therefore, we will take up the subjects in the order that you will need them and will use practical examples from the text that you have already studied. In this way you will be sure to learn the mathematics that you need, and you will also learn how to use it in practical examples.

The other reason that we break it up into several books spaced among the technical lessons is that we don't want to take you away from your technical progress long enough to study the math lessons all at once. By spacing the math lessons, you will be able to keep up with your technical lessons too. In this first lesson, we will do a number of problems in electronics which involve only addition, subtraction, multiplication and division. We will then start a detailed review of arithmetic starting with fractions and decimals. Examples and problems include circuit applications to help you learn how to make calculations in dc circuits. It may seem rather simple, however, you should read it all to be sure you remember it. Also, we have put in a few short cuts which you probably did learn in school and presented some of the material in a special way to help you later in your more advanced studies.

If mathematics has always bothered you before, don't be discouraged by the fact that you have to study it now. We present it very simply, and having a practical use for it makes it easier to understand.

Simple Arithmetic Review

Before going ahead with fractions and decimals, we want to point out here that the basic arithmetic operations of addition, subtraction, multiplication and division are important in electronics as they are in every other science. We assume that you are able to perform these basic operations; if you cannot, stop and get a book on basic arithmetic from your library. If you know how to add, subtract, multiply and divide, but have become rusty because you have not had occasion to perform these basic arithmetic operations, take some time now to do a little practicing. You will be surprised how quickly you will be able to pick up speed again after a little practice.

ADDITION

You might think that you will not have much occasion to use such a basic arithmetic operation as addition. However, this is not the case. As an example, in a series circuit, where two resistances are connected in series, the total resistance is equal to the sum of the two resistors. This means that if you have two 100-ohm resistors in series, to get the total resistance you add the resistance of the two resistors, 100 + 100 = 200. If you have a 100-ohm resistor in series with a 25-ohm resistor, to find the total resistance you add 100 + 25 = 125. If you have a number of resistors connected in

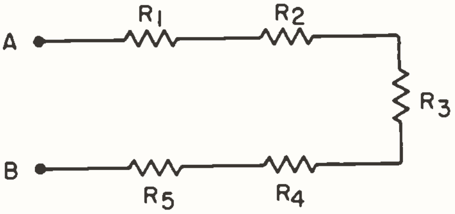


Fig. 1. A simple series circuit.

series, such as shown in the series circuit in Fig. 1, to get the total resistance between terminals A and B you add the resistance of the individual resistors. Suppose in this circuit that R1 = 100 ohms, R2 = 250 ohms, R3 = 150 ohms, R4 = 175 ohms, and R5 = 250 ohms. To find the total resistance between terminals A and B you write down the value of the individual resistors as shown and add.

$$\begin{array}{r}100\\250\\150\\175\\250\\\hline 925\end{array}$$

The preceding example is a simple example of addition in electronics to find the total resistance in a series circuit. Sometimes you have to be somewhat careful because the value of the resistors may vary quite widely and then it is important to get the digits arranged in the proper columns. In other words, you simply have to make sure that you arrange your work neatly so that the addition can be performed easily. As a second example, suppose the resistors have the following values: R = 5 ohms, R2 = 75 ohms, R3 = 6 ohms, R4 = 125, R5 = 32 ohms. To add the resistance of these resistors to get the total resistance between terminals A and B you write the resistors down as shown below and add.

$$\begin{array}{r}5\\75\\6\\125\\32\\\hline 243\end{array}$$

SUBTRACTION

There are occasions when you will have to subtract. In Fig. 2 we have shown a series circuit where the total resistance of the circuit is 197 ohms. The value of four of the resistors is known, but the value of the fifth resistance is unknown.

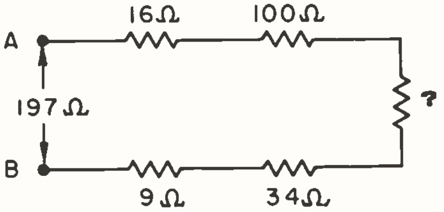


Fig. 2. A series circuit where one resistance is unknown.

You will remember that in a series circuit the total resistance is equal to the sum of the individual resistances. Therefore, the sum of the resistances must be 197 ohms. Since we know the value of four of the resistances we can find what their resistance is and then subtract this one value from 197 ohms to get the value of the unknown resistance.

To solve this problem we first write down the value of the known

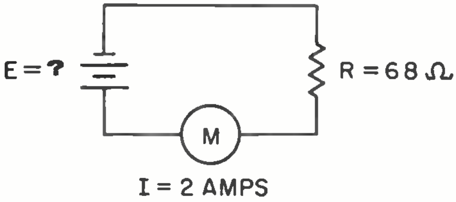


Fig. 3. An example where the formula E=IR is used to find the voltage.

resistors and add as shown:

$$\begin{array}{r}16\\100\\34\\9\\\hline 159\end{array}$$

Thus the total resistance of the four known resistors is 159 ohms. Since the total resistance is 197 ohms we can find the resistance of the unknown resistor by subtracting 159 from 197. We set the problem down as shown below and subtract:

$$\begin{array}{r}197\\-159\\\hline 38\end{array}$$

MULTIPLICATION AND DIVISION

Simple multiplication and division are also important in electronics. The various forms of Ohm's Law that you memorized demonstrate the importance of being able to multiply and divide.

An example of the use of the formula E = IR is shown in Fig. 3. In this circuit we know that the resistance is 68 ohms and the current flowing in the circuit is 2 amps and we want to find the value of the applied voltage. Using the formula E = IR in substituting 2 amps for I and 68 ohms for R we get:

$$\begin{aligned}E &= IR\\E &= 2 \times 68\\E &= 136 \text{ volts}\end{aligned}$$

In case you wonder why we used this particular form of Ohm's Law, the answer is that this is the form which is used to find the voltage, which is the unknown, when we know the value of the current and resistance, which are the known values. We have the unknown on one side of the equals sign and the two known values on the other side of the equals sign.

In the circuit shown in Fig. 4 we know the value of the voltage and resistance and want to find the current. Therefore, we will use a form of Ohm's Law which places the unknown on one side of the equals sign and the known values on the other side. This means that I must be on one side of the equals sign, and E and R on the other side. Thus, we use the formula I = E ÷ R. Substituting 32 volts for E and 16 ohms for R, we can get the value of the current:

$$\begin{aligned}I &= E \div R\\I &= 32 \div 16\\I &= 2 \text{ amps}\end{aligned}$$

Fig. 5 is an example in which we use the remaining form of Ohm's Law, R = E ÷ I. Again, in this case we have R, which is the unknown

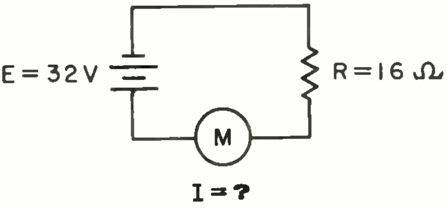


Fig. 4. An example of the formula I=E÷R used to find the current.

value, on one side of the equals sign, and the two known values E and I on the other side. Substituting 26 volts for E, and 2 amps for I we get:

$$R = E \div I$$
$$R = 26 \div 2$$
$$R = 13 \text{ ohms}$$

Notice that in each of the three preceding examples, not only did we carry out the mathematical operations to get a numerical answer, but we also gave the answer in its correct units. For example, in the first case, in the circuit shown in Fig. 3, where we wanted to find the value of the applied voltage, we gave the answer in volts. In the second case, where we had to find the current we gave the answer in amps. In the third case, where we had to find the resistance, we gave the answer in ohms. Remember this, it is important. You should always indicate the units of your answer. If you simply give a numerical answer, it has no meaning. If you are looking for the voltage in the circuit, the answer should be given in volts or some fraction or multiple of a volt. If you are looking for the current in a circuit then the answer should be given in amps or again in some fraction or a multiple of an ampere. Similarly, if you are looking for the resistance in a circuit, then the answer should be given in ohms or some fraction or multiple of an ohm.

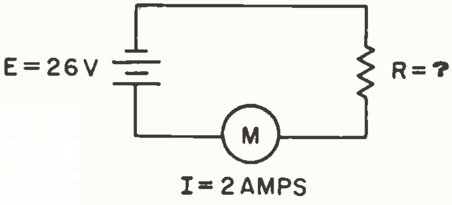


Fig. 5. An example of where the formula R = E ÷ I is used to find the resistance.

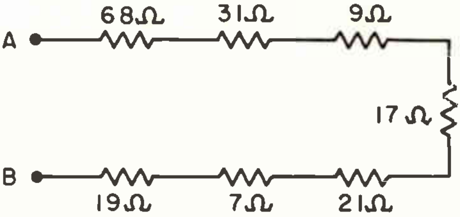


Fig. 6. Circuit for problem no. 1.

So far we have shown simple applications of addition, subtraction, multiplication and division in electronics. The examples were very simple, and in all probability you can handle problems of this type without any trouble. However, just to be sure, we have included ten practice problems which we have called, "Self-Test Questions." Even though you may think the problems are extremely simple, we urge you to do all ten to get practice finding the resistance in a circuit and in using Ohm's Law. A little practice now will help you become so familiar with these basic operations that when you have more complicated calculations to perform later, you will see that in many cases you're simply performing these simple operations several times.

You will find the answers to these questions at the back of the lesson along with a brief solution of each problem. Try to do each problem before you look at the answer so you will be working on your own. Be sure to check your answer and if you have made a mistake be sure to find out where the mistake is before going on.

SELF-TEST QUESTIONS

1. Find the total resistances between terminals A and B in the circuit shown in Fig. 6.

2. In the circuit shown in Fig. 7 the total resistance is 81 ohms. Find the resistance of the unknown resistor R.

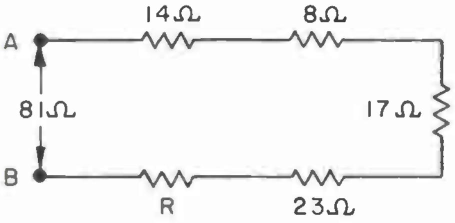


Fig. 7. Circuit for problem no. 2.

3. Find the total resistance between terminals A and B in the circuit shown in Fig. 8.

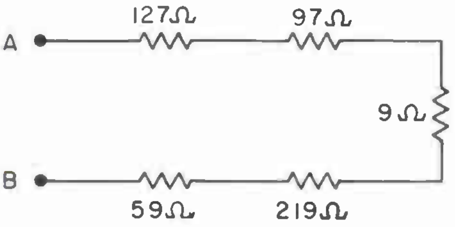


Fig. 8. Circuit for problem no. 3.

4. In the circuit shown in Fig. 9, the total resistance between terminals A and B is 823 ohms. Find the value of the unknown resistor R.

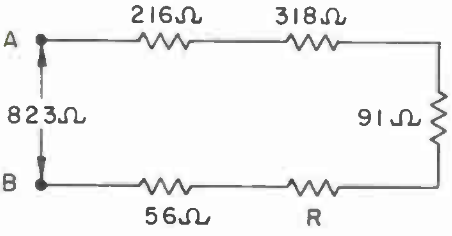


Fig. 9. Circuit for problem no. 4.

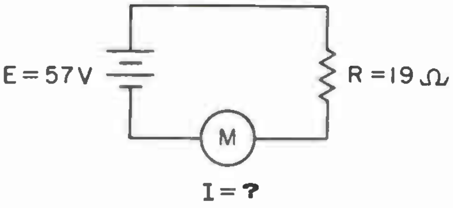


Fig. 10. Circuit for problem no. 5.

5. In the circuit shown in Fig. 10, the voltage is 57 volts, and the resistance in the circuit is 19 ohms. Find the current flowing in the circuit.

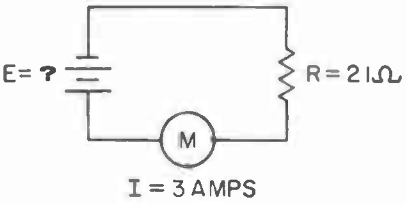


Fig. 11. Circuit for problem no. 6.

6. In the circuit shown in Fig. 11, the current flowing is 3 amps and the resistance in the circuit is 21 ohms. Find the value of the applied voltage.

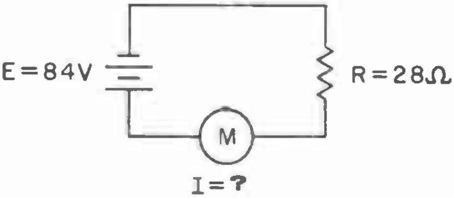


Fig. 12. Circuit for problem no. 7.

7. In the circuit shown in Fig. 12, find the current, if the applied voltage is 84 volts, and the resistance if the circuit is 28 ohms.

8. In the circuit shown in Fig. 13, the applied voltage is 96 volts, and the current in the circuit is 4 amps. Find the resistance in the circuit.

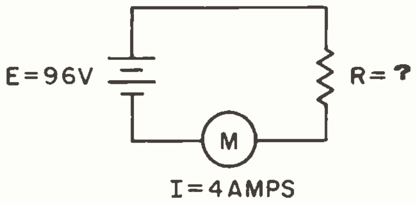


Fig. 13. Circuit for problem no. 8.

9. Find the voltage in the circuit shown in Fig. 14, if the current flowing in the circuit is 5 amps, and the resistance in the circuit is 17 ohms.

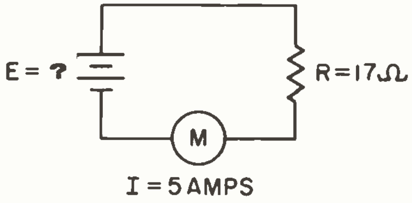


Fig. 14. Circuit for problem no. 9.

10. In the circuit shown in Fig. 15, the applied voltage is 32 volts, and the current flowing in the circuit is 2 amps. If R1 is equal to R2, find the value of these two resistors. (We have not covered an example exactly like this, but here is a chance for you to try a problem that is a little new on your own. Be sure to give it a good try, before looking at the solution at the back of the book.)

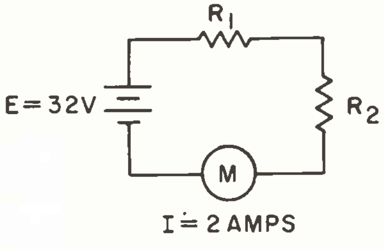


Fig. 15. Circuit for problem no. 10.

RULES OF ORDER

So far we have done problems involving addition, subtraction, multiplication and division. These are all very basic mathematical operations which we will use over and over again in our study of electronics. In the preceding problems, we have been concerned with just one operation at a time. In actual practice we will find a need to do several, or perhaps all these operations in order to find an answer to these problems.

While it may not seem at first glance that there is anything special about this, most of the time there will be a definite order in which we should do them. For example, take a simple problem like "find the value of 10 × 5 + 2." Let us look at this problem closely.

If we do the multiplication first and then the addition, we get 10 × 5 = 50, then we add the 2 and find the answer 52. However, if we look at the problem and say 5 + 2 = 7 and then 7 × 10 we come up with an answer of 70. As you can see, there is quite a difference between our first answer of 52 and our second answer of 70. Thus, the order in which we do a problem is important.

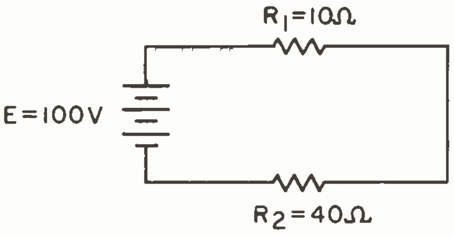


Fig. 16. Practical circuit where rules of order are important.

Let us take another more practical operation that we might find in our work in electronics. In the circuit shown in Fig. 16, we have a voltage supply of 100 volts and two resistors. One resistor is 10 ohms and the other is 40 ohms. Now the current in the circuit will be equal to this voltage divided by the resistance ($I = E \div R$). Let us take the problem mathematically and then substitute the values in the formula:

$$\begin{aligned} I &= E \div R \\ I &= 100 \div 10 + 40 \end{aligned}$$

Which operation do we do first? We know from our lessons on Ohm's Law that we are dealing with a total voltage of 100 volts. Therefore, we will be finding the total current, and to do this we will want to divide the total voltage by the total resistance. For this reason, we must add the two resistances first to get 10 + 40 = 50 ohms and then divide 100 by 50 to get a current of 2 amperes.

We did the problem this way because we know something about electronics; Ohm's Law states that total current equals total voltage divided by total resistance. We also know that the total resistance is equal to the sum of the resistances in the circuit. Therefore, in our problem, though we might not be aware of it, we actually thought this way:

$$\begin{aligned} I_T &= E_T \div R_T \\ R_T &= R_1 + R_2 \end{aligned}$$

so we kept the two resistances together.

If a person who did not know anything about electronics tried to work this problem he might not know the importance of keeping the two resistances together. Yet, one of the big advantages of using formulas in electronics is to express things simply so that problems can be easily worked out. Therefore, so that there will be no misunderstanding about the fact that R_1 and R_2 should be kept together, we enclose them in parentheses and write them as $(R_1 + R_2)$. Now the formula becomes:

$$I_T = E_T \div (R_1 + R_2)$$

Then we substituted to get:

$$\begin{aligned} & I_T = 100 \div (10 + 40) \\ \text{thus,}\ & I_T = 100 \div 50 \\ & \quad = 2 \text{ amps} \end{aligned}$$

If someone saw this problem without the parentheses, and he knew nothing about electronics, or math, other than addition and subtraction, multiplication and division, he might come up with a different answer. For example:

$$\begin{aligned} I &= E \div R \\ I &= 100 \div 10 + 40 \end{aligned}$$

Then, they might first divide 10 into 100 and get 10 so that for the current they would get

$$\begin{aligned} I &= 100 \div 10 + 40 = 10 + 40 \\ &= 50 \text{ amperes} \end{aligned}$$

From the preceding you can see the value of using parentheses, and also the need for establishing some rules in which the various arithmetic operations should be performed. These rules are called the rules of order and they insure that everyone everywhere will always know in what order to tackle a problem. The rules of order are very easy to learn and must always be followed. Always start at the left of a problem and work towards the right and do all the operations inside the parentheses first. Next, start at the left again and work towards the right and do all the multiplication and division in the order in which they occur. Then go back to the left of the problem again and once again work to the right doing the addition and subtraction.

By following these rules there is no possibility of coming up with the wrong answer or doing the wrong operations at the wrong time. A problem such as:

$$(6 + 3) \times 3 - 81 \div 9 + 4$$

can have only one answer. We start at the left and do the operations enclosed in the parentheses first. Since there is only one parenthesis, the first time, working from left to right, there is only one operation to perform: we add 6 + 3. Thus our problem becomes:

$$(6 + 3) \times 3 - 81 \div 9 + 4 =$$
$$9 \times 3 - 81 \div 9 + 4$$

Now we start at the left and go through from the left to the right again doing the multiplication and division in the order in which they occur. The first multiplication we hit is 9×3 and this is 27. The next operation we must perform is the division of 81 by 9; 9 goes into 81, 9 times. Since there are no other multiplications or divisions indicated these are the only operations we perform through this time. Thus we have:

$$9 \times 3 - 81 \div 9 + 4 = 27 - 9 + 4$$

Now we go through the problem again, working from the left to the right, doing the addition and subtraction.

$$27 - 9 = 18 \text{ and adding } 4$$

to this would give us 22. Thus we have

$$27 - 9 + 4 = 22$$

Sometimes all of the operations covered in the preceding example are not found in a problem. For example in the problem

$$8 \times 7 + 2 \times 4 - 16 \times 3$$

there are no parentheses and therefore we start right in going from left to right to do any multiplication or division that might be indicated. You will notice that in this problem there is no division so you simply go through doing the indicated multiplication. $8 \times 7 = 56$, $2 \times 4 = 8$ and $16 \times 3 = 48$; therefore, our problem becomes:

$$8 \times 7 + 2 \times 4 - 16 \times 3 =$$
$$56 + 8 - 48 = 16$$

The problem might have parentheses in it, but no multiplication or division. As long as the parentheses are there, you must perform the operations inside the parentheses. As an example, in the problem,

$$29 - (17 + 4) + 11$$

we must perform the operation 17 + 4 which is inside the parentheses first. Since $17 + 4 = 21$ our problem becomes:

$$29 - (17 + 4) + 11 = 29 - 21 + 11 = 19$$

Sometimes we need to do two or

more things in a special order. For this reason we also use brackets [ ] which are really a different kind of parentheses to indicate which comes first. Thus, we might have a problem:

$$5 \times 300 \div [2 \times (15+35)] + 20 - 5$$

Here we do the operations within the parenthesis, $(15 + 35) = 50$ first, and rewrite the bracket operation, replacing the $(15 + 35)$ with 50 to get

$$5 \times 300 \div [2 \times 50] + 20 - 5$$

then we do the operation inside the bracket to get:

$$2 \times 50 = 100$$

Now we rewrite the whole problem, placing everything inside the brackets with 100 and leaving the brackets out, thus, our problem becomes:

$$5 \times 300 \div 100 + 20 - 5$$

By following our rules of order, we start at the left and multiply 5×300 to get 1500, and then we divide this by 100 to get 15. Now we do our addition and subtraction: $15 + 20 - 5 = 35 - 5 = 30$ to find our final answer.

Since these rules of order are so important, let us state them again. First we do all the operations within the parentheses. Second, if we have one parenthesis within another, we do the operations inside the inner parenthesis first, and then do the operations within the outer parenthesis. When all the parenthetical operations are out of the way, we remove the parentheses, replacing the data within them with the answer we got. Then we rewrite our problem, starting at the left and working towards the right, doing all the multiplication and division in the order in which they occur. Then we return to the left and work to the right, doing the addition and subtraction in the order in which they occurred to get our answer.

You are going to run into problems in which you will have to perform the various operations in the correct order to get the correct answer. You will run into problems of this type in this lesson. Therefore, to get some practice doing the various operations in the right order, do the following five Self-Test Questions. You will find the answers in the back of the book.

SELF-TEST QUESTIONS

11. $25 + 16 \times 3 - 28 \div 7$
12. $5 \times (11 - 8) + 3 \times (7 - 5) \div 2$
13. $4 + (5+2) \times 20 - (10 - 6) \div (7 - 5)$
14. $3 \times 500 \div [2 \times (28+22)] + 25 - 6$
15. $95 \div (22 - 17) - 6 \times 2 - 3 + 8$

Fractions

In the simple circuit shown in Fig. 17, we have 100 volts applied to a circuit containing a total resistance of 100 ohms. This means that we will have a current flowing through the circuit of 1 ampere and a voltage drop across the resistances equal to the applied voltage of 100 volts. However, in this circuit we do not have a single 100-ohm resistor. Instead, we have two 50-ohm resistors in series, which makes up the total resistance of 100 ohms. Therefore, our voltage drop of 100 volts does not occur as one voltage, it occurs as two voltage drops of 50 volts across each resistor. In a case like this, where we have two equal voltage drops of 50 volts that add up to a total voltage of 100 volts, we often say that each drop of 50 volts is equal to one half of the total voltage. Just what do we mean when we say that we have one half of something? First, we mean that the "something," in this case 100 volts, is split up into parts. Further, since we have only two parts and they are equal we mean that the whole 100 volts is split into two equal parts. Thus, when we say one half of one hundred, it is like saying one of two equal parts of one hundred, or, more simply we mean 100 ÷ 2

Likewise, in a circuit such as the one shown in Fig. 18, the total voltage drop of 90 volts is split up into three equal parts of 30 volts each. This is just the same as saying that the voltage is split into thirds and one drop of 30 volts is equal to one-third of the total or 90 ÷ 3.

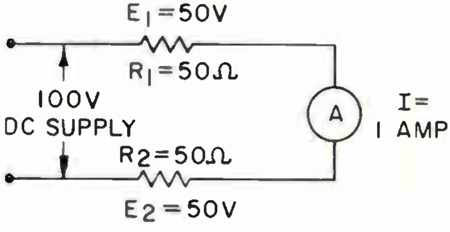


Fig. 17. One hundred volts divided into two equal parts or halves.

This can be written as $\frac{90}{3}$

100 ÷ 2 can be written as $\frac{100}{2}$

Whenever we split anything into parts we call the parts fractions. Thus, $\frac{100}{2}$ is a fraction and $\frac{90}{3}$ is also a fraction. Now these particular fractions can easily be worked out by performing the actual division so that $\frac{100}{2}$ is 100 ÷ 2, or 50; and $\frac{90}{3}$ is 90 ÷ 3, or 30. When they are worked out like this, 50 and 30 actually become whole numbers in themselves because they each represent an individual voltage drop. However, when we consider them as part of the total

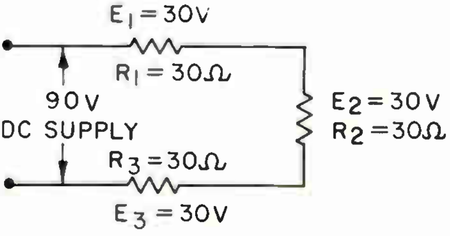


Fig. 18. Ninety volts divided equally into three parts or thirds.

voltage drop, they are both fractional parts of something and therefore they are also fractions.

When we want to represent 50 volts as some fraction of 100 volts, or 30 volts as a fraction of 90 volts, we would write them as $\frac{50}{100}$ or $\frac{30}{90}$, respectively. The fraction $\frac{50}{100}$ can be written more simply by dividing both the top of the fraction 50 and the bottom of the fraction 100 by the same number. For example, if we divide 100 by 50 we get 2 for an answer, and if we divide 50 by 50 we get an answer of 1. But placing the 1 in place of the 50 and the 2 in the place of the 100, our fraction becomes $\frac{1}{2}$, or one-half. Thus $\frac{50}{100}$ can be changed to $\frac{1}{2}$, or as we say, one-half, by dividing both the top and the bottom of the original fraction by 50. In the same way we can write $\frac{30}{90}$ or can simply divide both 30 and 90 by 30. This gives us $30 \div 30 = 1$ and $90 \div 30 = 3$. Then by replacing 30 with 1 and 90 with 3 we have the fraction $\frac{1}{3}$, which we pronounce "one-third." This fraction $\frac{1}{3}$ and the fraction $\frac{1}{2}$ which we found previously, are the simplest forms of the original fraction. We call this process of changing a fraction to its simplest form reducing the fraction.

Thus, in the circuit in Fig. 17 either one of the voltage drops can be considered several ways. They can be considered as one-half of a hundred which we write mathematically as $\frac{1}{2}$ of 100. They can be considered as $\frac{50}{100}$ which we can reduce to one-half or $\frac{1}{2}$ or they can be considered $\frac{100}{2}$ which is equal to 50. Now, these are all just different ways of saying the same thing. Likewise, any one of the voltage drops in the circuit in Fig. 18 can be expressed $\frac{1}{3}$ of 90, $\frac{30}{90}$ which equals $\frac{1}{3}$, or $\frac{90}{3}$ which equals 30.

We also have many other fractions. In fact, just as there is no limit to the largest number we can write by using combinations of digits from 0 to 9, there is no limit to the smallest part of something we can write by using the same digits. Just as $\frac{1}{2}$ means a whole something divided into two parts and $\frac{1}{3}$ means something divided into three parts, we can write $\frac{1}{6}$, which means the whole something is divided into six equal parts. We can continue in this way indefinitely. For example, $\frac{1}{64}$ means one of sixty four parts; $\frac{1}{128}$ means one of one hundred and twenty-eight equal parts and $\frac{1}{2465}$ means one of two thousand four hundred and sixty-five equal parts of something.

Notice, however, that a fraction by itself does not mean anything specific. For example, one half, one third, $\frac{1}{128}$, or $\frac{1}{2465}$ are fractions, but until we say what they are fractions of, we do not have any idea to what they are equal. One half of 50 volts is 25 volts, but as we have already seen one half of 100 volts is 50 volts. So a fraction to indicate anything definite must be accompanied by the whole something that we are talking about. Thus, we always say one-half of a gallon, or one-third of a quart, $\frac{1}{128}$ (pronounced one, one hundred twenty-eighth) of an ounce, one-fifth of the voltage, etc.

There are two parts to every fraction: there is the top part written above the line which is called the numerator, and there is the bottom part below the line called the denominator. The number in the numerator always tells us how many parts we have, and the number in the denominator tells us the size of the parts. Just as we can have one third of a gallon, it is also possible to have two $\frac{1}{3}$'s of a gallon which we would write $\frac{2}{3}$ of a gallon. The two indicates that we have two parts of a gallon and the three indicates that each part equals $\frac{1}{3}$ of a gallon.

There are also two kinds of fractions. One kind is called a proper fraction and always has a numerator that is smaller than the denominator, thus, $\frac{1}{3}$, $\frac{1}{2}$, $\frac{4}{7}$, and $\frac{5}{128}$ are all proper fractions because their numerator is smaller than the denominator. The other kind of fraction is called an improper fraction. An improper fraction is one in which the numerator is larger than the denominator, such as $\frac{100}{50}$, $\frac{100}{2}$, $\frac{755}{4}$, etc.

Improper fractions can always be converted into whole numbers or whole numbers and proper fractions. For example, the improper fraction $\frac{100}{50}$ becomes 2 if we perform the division and divide 50 into 100. The improper fraction $\frac{100}{2}$ becomes 50 if we divide 2 into 100. In the improper fraction $\frac{755}{4}$, when we divide 4 into 755, it will not go an even number of times. It will go one hundred and eighty-eight times with a remainder of 3. This means that in the improper fraction $\frac{755}{4}$ there are one hundred and eighty-eight whole parts and three $\frac{1}{4}$ parts. Thus we can write the improper fraction $\frac{755}{4}$

as $188\frac{3}{4}$

Both proper and improper fractions can be added, subtracted, multiplied and divided just like any whole numbers. After all, it is possible to have several halves of something, or several fifths of something which we might want to add or subtract from each other. The basic operations with fractions are much the same as with whole numbers, but there are certain rules that we must follow. In this section of the lesson we will learn the rules and see how to apply them.

ADDITION OF FRACTIONS

In adding fractions, we must remember one of the basic rules of any addition problem. Only like things can be added together. For example, we can add six oranges and four oranges and say we had ten oranges. Similarly, we can add twenty apples and nine apples and say we had twenty-nine apples. However, we could not add six apples and eight oranges and say we had fourteen oranges or fourteen apples. If we want to call the oranges and apples pieces of fruit then we could add the six and eight and say we had fourteen pieces of fruit because here we equated them to a common name. Similarly, we can add any number of volts to any other number of volts and get a total number of volts. We can add ohms to ohms and amperes to amperes, but we cannot add ohms to amperes or volts. The same rule applies to fractions except that we have an additional item of similarity to consider.

The denominators of fractions must be alike if we are going to add them. For example, one half a gallon can be added to another one half of a gallon to get a whole gallon. One third of a gallon can be added to another one third of a gallon to get two thirds of a gallon. Thus, fractions of like things with like denominators can be added together very simply by adding their numerators. Thus:

$$\frac{1}{2} + \frac{1}{2} = \frac{1 + 1}{2} = \frac{2}{2} = 1$$

$$\frac{2}{3} + \frac{1}{3} = \frac{2 + 1}{3} = \frac{3}{3} = 1$$

$$\frac{1}{3} + \frac{1}{3} = \frac{1 + 1}{3} = \frac{2}{3}$$

$$\frac{1}{5} + \frac{3}{5} = \frac{4}{5}$$

$$\frac{12}{64} + \frac{13}{64} = \frac{12 + 13}{64} = \frac{25}{64}$$

$$\frac{55}{137} + \frac{67}{137} = \frac{55 + 67}{137} = \frac{122}{137}$$

Now we have just seen that all fractions with like denominators can be added together simply by adding their numerators. However, fractions with unlike denominators cannot be added so simply. Before we can add fractions with unlike denominators, we must arrange them in a way that their denominators are all alike. This is called finding the lowest common denominator.

The Common Denominator.

When we first started our discussion of fractions, we discovered that we could "reduce" a fraction such as $\frac{50}{100}$ to a fraction $\frac{1}{2}$ by dividing both the numerator and the denominator by the same number. In this case, the number was 50 because with both the numerator and denominator of $\frac{50}{100}$ divided by 50, we get $\frac{1}{2}$. When we did this, we realized that either $\frac{50}{100}$ or $\frac{1}{2}$ meant exactly the same thing. Since either of these two ways of writing the fraction is correct, the two fractions must be equal. Thus, by dividing the numerator and the denominator by the same number, we have not changed the value of the number.

If this is true, we must also be able to multiply the numerator and denominator of a fraction by the same number without changing its value. 50 times both the numerator and denominator of $\frac{1}{2}$ is $50 \times 1 = 50$ and $50 \times 2 = 100$, or $\frac{50}{100}$. From this we can see that we can either multiply or divide the numerator and the denominator of a fraction by the same number without changing the value of the fraction. Accordingly, a fraction such as $\frac{1}{2}$ might be written in any one of several ways as follows:

$$\frac{1}{2} \times \frac{2}{2} = \frac{2}{4}, \frac{2}{4} \times \frac{2}{2} = \frac{4}{8}$$

$$\frac{1}{2} \times \frac{3}{3} = \frac{3}{6}, \frac{4}{8} \times \frac{4}{4} = \frac{16}{32}$$

$$\frac{16}{32} \times \frac{100}{100} = \frac{1600}{3200}$$

All these fractions are exactly equal to $\frac{1}{2}$ because they can all be reduced to $\frac{1}{2}$.

Likewise, we can change a fraction such as $\frac{1}{3}$ to any of the following fractions:

$$\frac{1}{3} \times \frac{3}{3} = \frac{3}{9}, \frac{1}{3} \times \frac{2}{2} = \frac{2}{6},$$

$$\frac{2}{6} \times \frac{5}{5} = \frac{10}{30}, \text{ etc.}$$

Let's see how this will help us in adding fractions. Suppose we want to add $\frac{1}{2} + \frac{1}{3}$. Since their denominators are not alike, we know that we can't add them as they are. However, suppose we change $\frac{1}{2}$ to $\frac{3}{6}$ which we can do by multiplying both the numerator and denominator by 3. Then, if we also change $\frac{1}{3}$ to $\frac{2}{6}$ which we can do by multiplying both numerator and denominator by 2, we now have two fractions which have the same denominator. They are $\frac{3}{6}$ and $\frac{2}{6}$ and they can be added together in the usual way to get $\frac{3+2}{6}$ or $\frac{5}{6}$. We have changed $\frac{1}{2}$ and $\frac{1}{3}$ to fractions with the same denominator so that they can be added without changing the values of the fractions themselves. $\frac{3}{6}$ is exactly the same as $\frac{1}{2}$ and $\frac{2}{6}$ is exactly the same as $\frac{1}{3}$. Added together they make $\frac{5}{6}$ or five-sixths.

When two fractions have the same denominator, we say they have a common denominator. When we change two or more fractions to equal fractions having the same common denominator so that we can add them, we call it finding the common denominator. Let's try a few more examples. For example:

$$\frac{1}{5} + \frac{1}{3} + \frac{4}{5} =$$

This is a very simple problem and we can readily see that both 5 and 3 will go into 15. As a matter of fact, 15 is the lowest common denominator of 5 and 3. 5 goes into 15 three times and therefore we change $\frac{1}{5}$ to a fraction and with 15 as the denominator we must multiply both the top and bottom by 3. Thus $\frac{1}{5}$ becomes $\frac{3}{15}$.

Similarly, 3 goes into 15 five times and therefore to change $\frac{1}{3}$ into a fraction with 15 as the denominator, we must multiply both the top of the fraction by 5 and the problem becomes $\frac{5}{15}$. To change $\frac{4}{5}$ into a fraction with 15 as the denominator, we again multiply the numerator and the denominator by 3 and therefore $\frac{4}{5}$ will become $\frac{12}{15}$. Thus our problem becomes:

$$\frac{1}{5} + \frac{1}{3} + \frac{4}{5} =$$

$$\frac{3 + 5 + 12}{15} =$$

$$\frac{20}{15}$$

While $\frac{20}{15}$ is the correct sum of the three fractions, it is not the usual custom to leave a fraction in the form of an improper fraction. We normally simplify the fraction. 15 goes into 20 once with a remainder of 5. Therefore,

$$\frac{20}{15} = 1\frac{5}{15}$$

Thus, we can say our answer is $1\frac{5}{15}$ However, $\frac{5}{15}$ can be simplified by dividing both the numerator and denominator by 5 and this would give us $\frac{1}{3}$. Therefore our sum is $1\frac{1}{3}$

If we look back at the original problem we can see that this is the answer we should expect. Notice that the first fraction we have is $\frac{1}{5}$ and the third one is $\frac{4}{5}$

$\frac{4}{5} + \frac{1}{5} = \frac{5}{5}$ which is equal to 1. Now we add $\frac{1}{3}$ to 1 and the answer is $1\frac{1}{3}$

In this problem it is quite obvious that the lowest common denominator of 5 and 3 is 15. However, suppose that instead of using 15 as the common denominator we had used 30. Both 5 and 3 will go into 30. This will not cause any difficulty; we will get exactly the same answer, but we will be working with bigger numbers because we did not use the lowest possible common denominator. Using 30 as the common denominator the problem becomes:

$$\frac{1}{5} + \frac{1}{3} + \frac{4}{5} =$$

$$\frac{6 + 10 + 24}{30} =$$

$$\frac{40}{30} =$$

$$1\frac{10}{30} =$$

$$1\frac{1}{3}$$

Similarly, if we had used 45 as a common denominator, once again we would get the same answer, but we would have to work with larger numbers. In this case the problem is,

$$\frac{1}{5} + \frac{1}{3} + \frac{4}{5} =$$

$$\frac{9 + 15 + 36}{45} =$$

$$\frac{60}{45} = 1\frac{15}{45} = 1\frac{1}{3}$$

In the preceding example it was easy to find the lowest common denominator. We were dealing with fifths and thirds and we got the lowest common denominator simply by multiplying 5 and 3 together. However, we cannot always do this and get the lowest common denominator. Suppose, for example, that you had the problem:

$$\frac{1}{6} + \frac{2}{9}$$

If we simply multiply the two denominators together we will get 6 × 9 = 54. Therefore, 54 is a common denominator. Now our problem is:

$$\frac{1}{6} + \frac{2}{9} =$$

$$\frac{9 + 12}{54} =$$

$$\frac{21}{54} = \frac{7}{18}$$

When we get the answer $\frac{21}{54}$ we immediately could see that 3 could be divided into both the numerator and the denominator and therefore we could reduce the fraction to $\frac{7}{18}$. Often when you get a fraction that can be reduced it is a sign that you did not use the lowest common denominator. However, as long as you reduce the fraction and perform your addition correctly, you will come out with the same answer as you would have if you had used the lowest common denominator. When you can find the lowest common denominator, it is best to use it, because you will be working with smaller numbers and there will be less chance of making a mistake.

There is an easy way to find the lowest common denominator. To do this take the denominators of the various fractions and factor them. Now you might wonder what a factor is. A factor is a number that when multiplied by another number gives you the original number. For example, 1 × 6 = 6. Therefore, 1 and 6 are factors of 6. Also 3 × 2 = 6 and therefore 3 and 2 are factors of 6. We call 3 and 2 prime factors because they themselves cannot be broken down into factors other than the number and one. In other words, you could say that 2 was equal to 2 × 1, but there is no other way you could factor it. The factor 2 still appears in 2 × 1; therefore, 3 and 2 are prime factors. When we factored 6 into 6 × 1 we did not factor it into prime factors because the 6 could be broken down into 3 and 2. Therefore, we break our denominators down into prime factors. The prime factors of 6 are 3 × 2 and the prime factors of 9 are 3 × 3. Now to find the lowest common denominator we look for common factors in the two denominators. We see immediately that we have a 3 in each denominator and therefore we write down 3 as one of the factors in our lowest common denominator and then place a stroke through the 3 in 3 ×2 and one 3 in 3 × 3. This leaves us two unused prime factors: the 2 from the factoring of 6 and one of the 3's from factoring 9. Since these are not common, but are different numbers, we must write both of these down beside the first three we set up in determining our lowest common denominator. Therefore, our lowest common denominator will be 3 × 2 × 3 = 18. Now if we add $\frac{1}{6} + \frac{2}{9}$ using 18 as the common denominator we have:

$$\frac{1}{6} + \frac{2}{9} =$$

$$\frac{3 + 4}{18} =$$

$$\frac{7}{18}$$

Now let's try another example. Let us do the problem,

$$\frac{3}{7} + \frac{5}{14} + \frac{8}{21}$$

We can find a common denominator in this problem by multiplying 7 × 14 × 21. However, you can see immediately if we do this we are going to have a rather large number as our common denominator. There is no point in getting involved in such big numbers because we see at a glance that 7, 14 and 21 are all divisible by 7. Therefore, it is worthwhile to factor the three denominators into prime factors to see if we can find the lowest common denominator. When we factor them we get:

$$\begin{aligned} 7 &= 7 \times 1 \\ 14 &= 7 \times 2 \\ 21 &= 7 \times 3 \end{aligned}$$

Now to get our lowest common denominator we first look for prime factors that are common to all three denominators. We notice first that 7 is a prime factor of all three so the first digit in our common denominator will be 7. Now we mark out the three 7's to be sure that we see they have been used. This leaves us with 1 in the first number, 2 in the next and 3 in the third. Therefore our complete lowest common denominator will be 7 × 1 × 2 × 3. This is equal to 42 and therefore 42 is the lowest common denominator. Now the problem becomes:

$$\frac{3}{7} + \frac{5}{14} + \frac{8}{21} =$$

$$\frac{18 + 15 + 16}{42} =$$

$$\frac{49}{42} = 1\frac{7}{42} = 1\frac{1}{6}$$

Let us do one more example. Add the following:

$$\frac{5}{18} + \frac{7}{27} + \frac{8}{45}$$

Again, we see immediately that if we find a common denominator by multiplying the three denominators together we will have a very large denominator. Therefore it is worthwhile to factor the denominator to see if we can find a smaller common denominator. 18 is equal to 9 × 2, but 9 is not a prime factor because it in turn can be factored into 3 × 3. Therefore, the prime factors of 18 are 3 × 3 × 2. Similarly, 27 and 45 can be factored into prime factors so that we will get:

$$\begin{aligned} 18 &= 3 \times 3 \times 2 \\ 27 &= 3 \times 3 \times 3 \\ 45 &= 3 \times 3 \times 5 \end{aligned}$$

Now to get our lowest common denominator we first look for factors that are common to the three numbers. We see that the first digit in each factor, which is 3, is common to all three so we put down the 3 as the first factor in our common denominator and then mark out the first 3 in each of the factors to indicate that this 3 has been used. The second digit is also a 3 so we use a second 3 in our lowest common denominator to give us 3 × 3 and we mark out the second 3 in each of the three numbers. Now this leaves us 2, 3, 5 and since these are not common in any of the three numbers we must include them in our lowest common denominator. Thus the lowest common denominator becomes 3 × 3 × 2 × 3 × 5. Multiplying these together we get 270 as the lowest common denominator. 18 goes into 270, 15 times. 27 goes into 270, 10 times and 45 goes into it 6 times. Therefore, our problem becomes:

$$\frac{5}{18} + \frac{7}{27} + \frac{8}{45} =$$

$$\frac{75 + 70 + 48}{270} =$$

$$\frac{193}{270}$$

So far, in finding common factors in the denominators in order to find the lowest common denominator, we have had a common factor in each of the denominators. However, this will not always be the case. Sometimes the common factor may appear in only two of the denominators. For example, in the problem,

$$\frac{1}{3} + \frac{1}{14} + \frac{1}{21}$$

we will have two different common factors which appear in only two of the denominators. Factoring the denominators we get:

$$\begin{aligned} 3 &= 3 \times 1 \\ 14 &= 2 \times 7 \\ 21 &= 3 \times 7 \end{aligned}$$

Now we start looking for common factors. Looking at the first number factored, we see that 3 is one of the factors so we place a stroke through it to indicate that we have used it. Looking at the second number we see that there is no 3 in its factors, but we see a 3 in the factors of the third number so we place a stroke through it indicating that it has been used and then put down 3 as the first number in the product which will eventually give us our lowest common denominator. Now looking at the first number again we see that the only factor left is 1, so we skip it and go on to the second number. Here we see that the factors are 2 and 7 and we take the first number which is a 2 and place a stroke through it. Now we write a × sign next to the 3 we have in the common denominator and place the 2 to the right of the × sign. This gives us 3 × 2 as the first two numbers in the common denominator. Since there is no 2 in the third group of factors we start over again. Looking at the second number we see that we still have a 7 left so we place a ×7 as the next factor in our common denominator and place a stroke through the 7 to indicate it has been used. Moving on to the third group of factors we see that we also have a 7 so we place a stroke through it to indicate that it has been used. Now the factors we have for our lowest common denominator are 3 × 2 × 7 and if we multiply these out we get 42 which is the lowest common denominator.

From the preceding we can see that some of the factors that go to make up our lowest common denominator might not appear in all of the numbers factored. However, when a common factor appears in two or three of the denominators that have been factored there is no point in placing it in the product that is going to make up our lowest common denominator more than once unless it appears in one of the factors more than once.

Another situation that you should be on the lookout for is a problem in which one of the denominators is a factor of the denominator in one of the other factors. When you run into this situation you can completely forget about the smaller denominator. For example, in the problem,

$$\frac{1}{3} + \frac{1}{7} + \frac{1}{14}$$

we see that 7 is a factor of 14. Therefore any number that 14 will divide into, 7 will divide into also. Therefore, we can simply forget about the 7 and find the lowest common denominator for 3 and 14.

You should also be on the lookout for a fraction which may not be reduced to its simplest form. For example, in the addition,

$$\frac{1}{5} + \frac{1}{4} + \frac{6}{8}$$

we could go ahead and find a common denominator. The lowest common denominator in this case is 40. However, $\frac{6}{8}$ can be reduced to $\frac{3}{4}$ by dividing the top and bottom of the fraction by 2. If we do this our problem becomes:

$$\frac{1}{5} + \frac{1}{4} + \frac{3}{4}$$

Now we see that our lowest common denominator is 20. In this problem it would not make a great deal of difference if we used 20 or 40 as a common denominator in performing the addition so long as we reduced the fraction to the simplest form after the addition; in some problems the lower figure could make the addition a great deal simpler.

Now to get practice adding fractions do the following problems. Be sure to work each problem carefully before looking at the answers at the back of the book. If by any chance you find that you have made a mistake in one of the additions, be sure to check your work over carefully comparing it with our solution to see where you made your mistake.

SELF-TEST QUESTIONS

16. $\frac{3}{7} + \frac{5}{7} + \frac{6}{7}$

17. $\frac{1}{2} + \frac{1}{3} + \frac{1}{12}$

18. $\frac{1}{2} + \frac{1}{3} + \frac{1}{5}$

19. $\frac{3}{8} + \frac{1}{2} + \frac{3}{4}$

20. $\frac{3}{4} + \frac{1}{16} + \frac{1}{8}$

21. $\frac{1}{3} + \frac{1}{7} + \frac{3}{14}$

22. $\frac{6}{23} + \frac{8}{46} + \frac{19}{69}$

23. $\frac{1}{5} + \frac{2}{9} + \frac{3}{11}$

24. $\frac{1}{9} + \frac{3}{4} + \frac{1}{8}$

25. $\frac{7}{25} + \frac{9}{35} + \frac{2}{5}$

SUBTRACTION OF FRACTIONS

Subtracting fractions is just the reverse of adding fractions. All the rules that apply to the addition of fractions apply to subtraction. First, the fractions must be parts of like things and they must have the same denominator in order to subtract them. If they do not have a common denominator, we must find the lowest common denominator for them. We do this in exactly the same way as we did for addition.

When we are subtracting one fraction from another, we subtract only the numerators and when we have finished our subtraction, we always reduce the answer as much as possible. For example:

$$\frac{5}{6} - \frac{1}{6} = \frac{5 - 1}{6} = \frac{4}{6} = \frac{2}{3}$$

To subtract $\frac{1}{3}$ from $\frac{1}{2}$, we must find the lowest common denominator which is 6. Thus the subtraction becomes:

$$\frac{1}{2} - \frac{1}{3} = \frac{3 - 2}{6} = \frac{1}{6}$$

As you can see, the procedure is essentially the same as adding fractions, however, in this case we subtract the numerators instead of adding them.

Just as in problems involving addition of fractions where we had more than two fractions to add, sometimes we have several subtractions to perform. You proceed in essentially the same way. For example, in the problem,

$$\frac{11}{12} - \frac{1}{4} - \frac{1}{3}$$

we first find the lowest common denominator, which in this case is 12. Then we perform first one subtraction and then the other. If we wanted to do so we could add the numerators of the two fractions to be subtracted and then perform a single subtraction. The problem will be worked out as follows:

$$\frac{11}{12} - \frac{1}{4} - \frac{1}{3} =$$

$$\frac{11 - 3 - 4}{12}$$

Now we can subtract 3 from 11 which would give us 8 and 4 from 8 which gives a remainder of 4 and an answer of $\frac{4}{12}$ which we reduce to $\frac{1}{3}$. The other method would be to first add the 3 and 4 together to get 7 and then subtract the 7 from 11 which again gives us $\frac{4}{12}$. We get the same answer in either case so you can do the problem whichever way you want. The usual procedure is to start at the left and go from left to right and perform one subtraction after the other.

There is no way to really learn how to subtract fractions other than by doing problems involving subtraction of fractions. Therefore, you should do the following problems. Do each problem carefully before looking at the answers in the back of the book. Once again, if you should fail to get the same answers we got, be sure to check your work to find out where the mistake is.

SELF-TEST QUESTIONS

26. $\frac{5}{7} - \frac{3}{7}$

27. $\frac{2}{3} - \frac{1}{2}$

28. $\frac{7}{10} - \frac{3}{5}$

29. $\frac{8}{9} - \frac{2}{5}$

30. $\frac{3}{4} - \frac{3}{8}$

31. $\frac{25}{27} - \frac{1}{3}$

32. $\frac{3}{4} - \frac{1}{6} - \frac{1}{3}$

33. $\frac{7}{8} - \frac{1}{9} - \frac{1}{5}$

34. $\frac{4}{5} - \frac{3}{25} - \frac{3}{50}$

35. $\frac{35}{36} - \frac{3}{9} - \frac{1}{4}$

MIXED NUMBERS

Often you will have to add and subtract mixed numbers. You will remember that a mixed number is a number made up of a whole number and a fraction. For example, add,

$$1\frac{2}{3} + 2\frac{1}{6}$$

There are two ways you can do this problem. One method is to add the whole numbers first and then add the fractions and then add the sum of the fractions and the sum of the whole numbers together. The other method is to convert each mixed number to an improper fraction and then go ahead and perform the addition and then convert the answer back to a mixed number. Usually the easiest way to do this type of problem is to add the whole numbers and the fractions separately. However, we will go through both methods here. Using the first method first, that is of adding the whole numbers and fractions separately we get:

$$1\frac{2}{3} + 2\frac{1}{6} =$$

$$1 + 2 + \frac{2}{3} + \frac{1}{6} =$$

$$3 + \frac{4 + 1}{6} =$$

$$3 + \frac{5}{6} = 3\frac{5}{6}$$

As you can see, in using this method we simply add the whole numbers and then add the fractions, following the same procedure as we used before, that of finding the lowest common denominator and then adding.

When we convert the numbers to improper fractions we sometimes have to deal with slightly larger numbers, but this method works out equally as well. For example,

$1\frac{2}{3}$ can be converted to $\frac{5}{3}$

1 is $\frac{3}{3}$ and $\frac{3}{3} + \frac{2}{3} = \frac{5}{3}$

$2\frac{1}{6}$ can be converted to $\frac{13}{6}$

Now our problem becomes

$$\frac{5}{3} + \frac{13}{6}$$

And using the lowest common denominator of 6 we get:

$$\frac{10 + 13}{6} = \frac{23}{6}$$

$$\frac{23}{6} =$$

$$3\frac{5}{6}$$

As you see, we got $3\frac{5}{6}$ as the answer both ways. One method is as good as the other; use whichever method you prefer.

Subtraction of mixed numbers can be performed in essentially the same way as addition. However, sometimes we come up with a small complication in subtraction. Let us look at the problem:

$$3\frac{3}{4} - 2\frac{1}{8}$$

We can perform this subtraction by subtracting the whole numbers first and then by subtracting the fractions, using the same method as we used previously. Following this procedure the problem becomes:

$$3\frac{3}{4} - 2\frac{1}{8} =$$

$$3 - 2 + \frac{3}{4} - \frac{1}{8} =$$

$$1 + \frac{6 - 1}{8} =$$

$$1 + \frac{5}{8} =$$

$$1\frac{5}{8}$$

We can also perform this subtraction by converting both numbers to improper fractions and then subtracting. To convert $3\frac{3}{4}$ to a mixed number we multiply 3×4 which gives us 12; there are twelve quarters in 3 plus 3 which gives us $\frac{15}{4}$

$2\frac{1}{8}$ becomes $2 \times 8 + 1 = \frac{17}{8}$

Now our problem is

$$\frac{15}{4} - \frac{17}{8}$$

As in previous subtraction problems we must convert to the lowest common denominator which in this case is 8 so we get:

$$\frac{30}{8} - \frac{17}{8} =$$

$$\frac{13}{8} =$$

$$1\frac{5}{8}$$

Once again, you see that we get the

same answer so it does not matter which method you use. The first method is simple enough in most cases, but sometimes when using this method you have to borrow in order to perform one of the subtractions. We can best see what this involves by looking at the example:

$$4\frac{1}{8} - 2\frac{3}{4}$$

If we proceed with the subtraction by subtracting the whole numbers first, we get 4 - 2 which is 2. Now when we try to subtract the fractions we have

$$\frac{1}{8} - \frac{3}{4}$$

and when we convert this to the lowest common denominator which is 8 we have

$$\frac{1 - 6}{8}$$

If we subtract 6 from 1 we end up with a minus answer. Therefore, to perform this subtraction we must borrow from the whole number. In the original problem the whole number was 4 - 2 which gave us 2. We can change 2 to $1 + \frac{8}{8}$ and then add the $\frac{8}{8}$ to $\frac{1}{8}$ and get $\frac{9}{8}$

Now we can subtract

$\frac{6}{8}$ from $\frac{9}{8}$ and get $\frac{3}{8}$

and our answer is $1\frac{3}{8}$

If you do this problem by converting to improper fractions, you do not run into this problem.

$4\frac{1}{8}$ becomes $4 \times 8 + 1 = \frac{33}{8}$

$2\frac{3}{4}$ becomes $2 \times 4 + 3 = \frac{11}{4}$

Now our problem is

$$\frac{33}{8} - \frac{11}{4} =$$

$$\frac{33 - 22}{8} = \frac{11}{8} = 1\frac{3}{8}$$

Some problems will involve addition and subtraction of mixed numbers. When you encounter this type of problem you can do the addition and subtraction of the whole numbers first and then the addition and subtraction of the fractions or you can convert all the numbers to improper fractions and work the problem this way. As an example, consider the problem:

$$7\frac{1}{4} - 2\frac{3}{8} + 4\frac{7}{8} - 3\frac{9}{16}$$

Adding and subtracting the whole numbers we get 7 - 2 + 4 - 3 = 6. Now we must handle the fractions and to do this we must convert to the lowest common denominator which in this problem is 16. Thus, we have:

$$\frac{4 - 6 + 14 - 9}{16}$$

Now adding together the numbers to be added and at the same time adding the numbers that are to be subtracted we get:

$$\frac{4 + 14 - 6 - 9}{16} =$$

$$\frac{18 - 15}{16} = \frac{3}{16}$$

Therefore, our complete answer is

$$6\frac{3}{16}$$

Now if we decide to do the problem by converting the fractions to improper fractions

$7\frac{1}{4}$ becomes $7 \times 4 + 1 = \frac{29}{4}$

$2\frac{3}{8}$ becomes $2 \times 8 + 3 = \frac{19}{8}$

$4\frac{7}{8}$ becomes $4 \times 8 + 7 = \frac{39}{8}$

and $3\frac{9}{16}$ becomes $3 \times 16 + 9 = \frac{57}{16}$

Thus our problem becomes:

$$\frac{29}{4} - \frac{19}{8} + \frac{39}{8} - \frac{57}{16}$$

and changing these fractions to a common denominator of 16 we get:

$$\frac{116 - 38 + 78 - 57}{16} =$$

$$\frac{99}{16} = 6\frac{3}{16}$$

Once again we have the same answer so the choice of which way you do the problem is yours. Decide on which way you think is the easier and then do all of them the same way. Usually it is best to stick to one method rather than jump back and forth between the two because this often results in confusion. Now to get practice handling mixed numbers do the following problems. Again, be careful of your work to be sure that you get the right answer. Be sure you check each problem carefully before comparing your answers with ours which are at the back of the book.

SELF-TEST QUESTIONS

36. $1\frac{1}{4} + 2\frac{1}{5}$

37. $2\frac{1}{2} + 3\frac{1}{3} + 1\frac{1}{6}$

38. $4\frac{7}{8} - 3\frac{1}{4}$

39. $5\frac{1}{8} - 2\frac{3}{7}$

40. $8\frac{1}{9} - 3\frac{2}{7} - 2\frac{2}{3}$

41. $\frac{1}{7} + \frac{8}{9} - \frac{1}{3}$

42. $\frac{3}{4} - \frac{1}{9} + \frac{3}{18} - \frac{1}{2}$

43. $4\frac{3}{8} + 1\frac{1}{4} - 2\frac{1}{7}$

44. $1\frac{7}{8} - 3\frac{1}{7} - 1\frac{1}{6} + 8\frac{2}{9}$

45. $6\frac{1}{3} - 4\frac{3}{4} + \frac{1}{9} - 1\frac{1}{3}$

MULTIPLYING FRACTIONS

There is a very simple rule that we follow in multiplying fractions. We simply multiply the numerators of the fractions together to get the numerator of the product and multiply the denominators together to get the denominator of the product. For example, $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$. We have multiplied the two numerators, 1 × 1 and got 1 as the product and then multiplied the two denominators, 2 × 2 and got 4 as the new denominator. Actually, we can take the problem $\frac{1}{2} \times \frac{1}{2}$ and write it as $\frac{1 \times 1}{2 \times 2}$ and then it becomes quite obvious that our product will become $\frac{1}{4}$. It might at first disturb you that when you multiply two fractions together the product is smaller than either fraction. However, if you consider the multiplication as $\frac{1}{2}$ of $\frac{1}{2}$, you will see that the resultant should be $\frac{1}{4}$ In other words, you have $\frac{1}{2}$ of something and you are taking $\frac{1}{2}$ of that so that the resultant will be $\frac{1}{4}$

Often after you have multiplied two fractions together you can reduce the fraction to its simplest form. For example:

$$\frac{2}{3} \times \frac{1}{2} =$$

$$\frac{2 \times 1}{3 \times 2} =$$

$$\frac{2}{6} = \frac{1}{3}$$

We can also multiply several fractions together at once. For example, $\frac{2}{9} \times \frac{3}{4} \times \frac{5}{7}$ would be set up for the multiplication like this:

$$\frac{2 \times 3 \times 5}{9 \times 4 \times 7} = \frac{6 \times 5}{36 \times 7} =$$

$$\frac{30}{252} = \frac{15}{126} = \frac{5}{42}$$

In this example the resultant fraction is reducible: this usually means that it is possible to reduce some of the fractions before we perform the multiplication by what we call division or cancellation, before we multiply. Thus, in the problem,

$$\frac{2 \times 3 \times 5}{9 \times 4 \times 7}$$

the first number in the numerator is 2 which can be divided into the second number in the denominator which is 4. This would leave us:

$$\frac{\overset{1}{\cancel{2}} \times 3 \times 5}{9 \times \underset{2}{\cancel{4}} \times 7}$$

We can also divide the 3 in the numerator into 9 in the denominator which leaves us:

$$\frac{\overset{1}{\cancel{2}} \times \overset{1}{\cancel{3}} \times 5}{\underset{3}{\cancel{9}} \times \underset{2}{\cancel{4}} \times 7}$$

Now when we multiply we have 1 × 1 × 5 or 5 in the numerator, and 3 × 2 × 7 or 42 in the denominator and we get our answer $\frac{5}{42}$ directly. Thus, by cancellation before we multiply we simplify the problem.

You can perform your multiplication of fractions either way: you can multiply them out and then cancel later or you can do the cancellation first. Usually the best method is to do the cancellation first because you will then be multiplying smaller numbers together and there will be less chance of your making an error.

For practice do the following multiplication problems. As before, be sure to do each problem carefully before checking your answer with those given in the back of the book and if you do make a mistake be sure to find out where your mistake lies before leaving the problem.

SELF-TEST QUESTIONS

46. $\frac{1}{3} \times \frac{1}{4}$

47. $\frac{1}{7} \times \frac{2}{9}$

48. $\frac{3}{4} \times \frac{3}{8}$

49. $\frac{7}{8} \times \frac{4}{7}$

50. $\frac{5}{13} \times \frac{26}{30}$

51. $\frac{3}{7} \times \frac{7}{8} \times \frac{2}{3}$

52. $\frac{3}{8} \times \frac{16}{19} \times \frac{19}{21}$

53. $\frac{1}{8} \times \frac{8}{9} \times \frac{9}{23}$

54. $\frac{4}{7} \times \frac{21}{28} \times \frac{7}{9}$

55. $\frac{18}{20} \times \frac{30}{36} \times \frac{2}{3}$

DIVIDING FRACTIONS

Division of whole numbers is just the opposite of multiplication of whole numbers. For example, if we are multiplying 3 × 4 we get 12. If we divide 4 into 12 we get 3. Likewise, division of fractions is just the reverse of multiplication of fractions. In division we have a fraction for our dividend and a fraction for our divisor and we are asked what number or fraction, when multiplied by the divisor, will give us the product that equals the dividend.

If $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$

$\frac{1}{4} \div \frac{1}{2}$ must equal $\frac{1}{2}$

Likewise,

if $\frac{2}{3} \times \frac{1}{2} = \frac{2}{6}$ or $\frac{1}{3}$

then $\frac{1}{3} \div \frac{1}{2}$ must equal $\frac{2}{3}$

To divide one fraction into another, all we do is invert the divisor, in other words, we turn it upside down, and then multiply the two fractions together. Thus, in the problem,

$$\frac{1}{6} \div \frac{2}{3}$$

$\frac{2}{3}$ is the divisor so to perform the division we invert it and multiply so that our problem becomes:

$$\frac{1}{6} \div \frac{2}{3} =$$

$$\frac{1}{6} \times \frac{3}{2} = \frac{1}{4}$$

Likewise,

$\frac{3}{7} \div \frac{5}{6}$ becomes $\frac{3}{7} \times \frac{6}{5} = \frac{18}{35}$

When performing the multiplication it is usually worthwhile to see if it is possible to do any cancelling. This will simplify the problem and usually you will be working with smaller numbers so there is less chance of your making a mistake. For example, in the problem,

$$\frac{3}{4} \div \frac{9}{16}$$

we invert the $\frac{9}{16}$ and multiply so we have

$$\frac{3}{4} \times \frac{16}{9}$$

We immediately see that the 4 in the denominator of $\frac{3}{4}$ will go into 16 in the numerator of $\frac{16}{9}$ four times. At the same time we see that the 3 in the numerator of the fraction $\frac{3}{4}$ will go into the 9 in the denominator of $\frac{16}{9}$ three times. Thus, dividing by 4 and 3 we get:

$$\frac{\overset{1}{\cancel{3}}}{\underset{1}{\cancel{4}}} \times \frac{\overset{4}{\cancel{16}}}{\underset{3}{\cancel{9}}} =$$

$$\frac{4}{3} = 1\frac{1}{3}$$

In some problems we will have more than one division to perform. In this case you can set the problem up as one problem by inverting all the divisors. For example, in the problem,

$$\frac{3}{8} \div \frac{7}{16} \div \frac{3}{7}$$

we have two divisors. The first divisor is $\frac{7}{16}$ which when inverted becomes $\frac{16}{7}$ and the second divisor which is $\frac{3}{7}$ becomes $\frac{7}{3}$ when it is inverted. Thus, if we invert both divisors our problem becomes:

$$\frac{3}{8} \times \frac{16}{7} \times \frac{7}{3}$$

Again, we can multiply all the numbers in the numerator to get the numerator product and then multiply all the numbers in the denominator to get the denominator product, but it is easier if we cancel first. Notice that in the first fraction, which is $\frac{3}{8}$, the 3 in the numerator will cancel the 3 in the denominator of the last fraction, $\frac{7}{3}$. Similarly, the 8 in the denominator of the first fraction will go into the 16 of the numerator of the second fraction twice. The 7 in the denominator of the second fraction will go into the 7 in the numerator of the third fraction. Thus when we perform the divisions our problem becomes:

$$\frac{\cancel{3}}{\underset{1}{\cancel{8}}} \times \frac{\overset{2}{\cancel{16}}}{\cancel{7}} \times \frac{\cancel{7}}{\cancel{3}} =$$

$$\frac{2}{1} = 2$$

Now you need to get practice dividing fractions so do the following problems carefully and compare your answers with those at the back of the book to be sure that you have the correct answer for each problem.

SELF-TEST QUESTIONS

56. $\frac{1}{3} \div \frac{2}{9}$

57. $\frac{2}{7} \div \frac{3}{7}$

58. $\frac{3}{4} \div \frac{9}{16}$

59. $\frac{47}{49} \div \frac{1}{7}$

60. $\frac{19}{23} \div \frac{38}{41}$

61. $\frac{2}{7} \div \frac{1}{14} \div \frac{1}{2}$

62. $\frac{1}{9} \div \frac{2}{3} \div \frac{3}{7}$

63. $\frac{2}{11} \div \frac{4}{7} \div \frac{3}{14}$

64. $\frac{2}{9} \div \frac{4}{5} \div \frac{5}{8}$

65. $\frac{13}{15} \div \frac{2}{5} \div \frac{4}{9}$

MIXED NUMBERS AND IMPROPER FRACTIONS

To multiply and divide mixed numbers, you should convert the mixed number to an improper fraction and then proceed as you do with simple fractions. For example, in the problem,

$$1\frac{3}{4} \times 2\frac{2}{7}$$

we convert the $1\frac{3}{4}$ to fourths; to do this we multiply 1 × 4 which gives us 4 plus 3 or the total of $\frac{7}{4}$. We convert the $2\frac{2}{7}$ to sevenths by multiplying 2 × 7 to get 14 plus 2 equals $\frac{16}{7}$. Our problem then becomes:

$$\frac{7}{4} \times \frac{16}{7}$$

and rather than perform the indicated multiplications we cancel the 7 in the numerator of $\frac{7}{4}$ and the 7 in the denominator of $\frac{16}{7}$. Similarly, we divide 4 into the denominator of $\frac{7}{4}$ and 4 into the numerator in the fraction $\frac{16}{4}$. Thus, our problem becomes:

$$\frac{\cancel{7}}{\underset{1}{\cancel{4}}} \times \frac{\overset{4}{\cancel{16}}}{\cancel{7}} =$$

$$\frac{4}{1} = 4$$

We do our division the same way: we convert both mixed numbers to improper fractions. For example:

$$2\frac{5}{7} \div 1\frac{3}{7} =$$

$$\frac{19}{7} \div \frac{10}{7} =$$

$$\frac{19}{\cancel{7}} \times \frac{\cancel{7}}{10} = 1\frac{9}{10}$$

Sometimes you will run into problems with both multiplication and division involving mixed numbers. To do these problems you convert the mixed numbers to improper fractions and then go ahead and proceed as you would in a multiplication and division of simple fractions. Remember that to divide you simply invert the divisor and multiply. For example:

$$3\frac{1}{4} \div 1\frac{1}{8} \times 3\frac{6}{13} =$$

$$\frac{13}{4} \div \frac{9}{8} \times \frac{45}{13} =$$

$$\frac{\cancel{13}}{\cancel{4}} \times \frac{\overset{2}{\cancel{8}}}{\cancel{9}} \times \frac{\overset{5}{\cancel{45}}}{\cancel{13}} =$$

$$\frac{10}{1} = 10$$

If you worked all these preceding multiplication and division problems you should have no difficulty doing the following problems involving mixed numbers. Be sure to check your work carefully as you go along and if you should get the wrong answer be sure to find out where you made your mistake before leaving the question.

SELF-TEST QUESTIONS

66. $1\frac{1}{4} \times 2\frac{1}{2}$

67. $2\frac{3}{8} \times 4\frac{1}{7}$

68. $4\frac{3}{7} \times 5\frac{4}{9}$

69. $6\frac{7}{8} \div 2\frac{1}{4}$

70. $5\frac{1}{8} \div 3\frac{1}{7}$

71. $8\frac{2}{9} \div 5\frac{1}{6}$

72. $8\frac{1}{9} \times 3\frac{1}{5} \div 9\frac{1}{7}$

73. $6\frac{2}{3} \div 2\frac{2}{9} \times 4\frac{3}{4}$

74. $3\frac{1}{4} \div 8\frac{1}{2} \times 2\frac{1}{8}$

75. $1\frac{7}{8} \div 6\frac{6}{9} \times 2\frac{1}{2}$

RULES OF ORDER

In some problems you will have addition, subtraction, multiplication and division all in the same problem. In problems of this type you follow the rules of order that we established for addition, subtraction, multiplication and division of whole numbers. You will remember that you do any operations enclosed inside of brackets or parentheses first. Then going through the problem, working from the left to the right, you do the multiplication and division in the order in which they occur and then you go back to the left and work through to the right doing the addition and subtraction this time all the way through.

Where there is a multiplication and division side by side, rather than perform either operation separately, you can set the problem up so you can cancel as you did in earlier examples and, in this way, sometimes save yourself some work.

We are not going to give you any detailed examples on how to do problems of this type because you have done all the operations involved many times and you should be able to work out this type of problem. However, we have included five problems at the end of this section for you to do. Try working these problems and then after you have worked them out check with the answers at the back of the book to see how you made out. If you have made any errors be sure to check the sample solution carefully to be sure where your error lies.

SELF-TEST QUESTIONS

76. $\frac{1}{2} + \frac{1}{4} \times \frac{3}{5} - \frac{1}{10} + \frac{1}{10} \div \frac{3}{5}$

77. $\frac{1}{2} \div \frac{1}{8} \times \frac{5}{7} - \frac{1}{8} \times \frac{8}{9} \div \frac{1}{3}$

78. $\frac{1}{2} - \frac{1}{4} \times \frac{1}{3} + \frac{1}{2} \div \frac{3}{4} - \frac{1}{6}$

79. $1\frac{1}{4} + 1\frac{3}{8} \times \frac{3}{8} \div 2\frac{3}{4} - 3 \times \frac{1}{9} \div \frac{3}{4}$

80. $\left(\frac{3}{4} + \frac{1}{8}\right) \div \frac{7}{8} - \left(\frac{3}{4} - \frac{1}{8}\right) \times \frac{8}{9}$

SUMMARY

We have now gone through all the rules for operating with fractions and we can summarize our results for easy reference as follows:

(1) The product of two or more fractions is a new fraction whose numerator is a product of the numerators of all these fractions, and whose denominator is the product of the denominators of all the factors. Any whole number may be considered as a fraction with a denominator of 1. For instance, 127 means $\frac{127}{1}$

(2) The quotient of two fractions is the product of the dividend times the divisor inverted (turned upside down).
Notice that neither multiplication nor division of fractions require the use of a common denominator.

(3) To add fractions, they must be reduced to equivalent fractions with a common denominator; then their sum is the sum of the numerators divided by the common denominator.

(4) Similarly, to subtract one fraction from another, we must use a common denominator and the difference is the difference of the numerators, divided by the common denominator.

(5) All results should be reduced to their simplest form by dividing both numerator and denominator by the largest common divisor.

Decimals

A decimal is simply a fraction whose denominator is 10 or some multiple of 10, for example, 100, 1000 etc. For example, the fraction $\frac{6}{10}$ can be written as .6 and .6 is called a decimal or a decimal fraction. We omit the denominator because it is understood. The decimal fraction $\frac{65}{100}$ can be written as .65 and the fraction $\frac{655}{1000}$ can be written as .655

At first you might think decimals are something new or something difficult to deal with, but this is not the case. You deal with decimals everyday when you handle money. You are acquainted with these coins: a cent, a nickel, a dime, a quarter dollar, and a half dollar.

$\frac{1}{100}$, $\frac{1}{20}$, $\frac{1}{10}$, $\frac{1}{4}$, $\frac{1}{2}$ of a dollar

or $\frac{1}{100}$, $\frac{5}{100}$, $\frac{10}{100}$, $\frac{25}{100}$ and $\frac{50}{100}$ of a dollar.

It is just second nature to write these as \$.01, \$.05, \$.10, \$.25 and \$.50. That is, \$1.25 means one dollar and twenty-five cents or $1\frac{25}{100}$ dollars. On this basis you can easily add up such amounts as:

$$\begin{array}{r} \$\ 3.25 \\ 7.12 \\ 2.84 \\ 6.33 \\ \hline \$19.54 \end{array}$$

Just as we separate the dollars and cents (the cents are hundreths of a dollar), we can separate our whole numbers and fractions with a point. This is called a decimal point, and we can write all our fractions with denominators of 10, 100, 1000, etc. as whole numbers by learning to use this decimal point. To do this, we use the first place to the right of the point for tenths, the next for hundredths, the third for thousandths etc.

In this fashion $1\frac{1}{10}$ becomes 1.1

$1\frac{2}{10}$ becomes 1.2

$1\frac{1}{100}$ becomes 1.01

and $1\frac{1}{1000}$ can be written as 1.001

CONVERTING FRACTIONS TO DECIMALS

With a little practice many fractions can be converted to decimals simply by inspection. This is true of fractions whose denominators are multiples of 10. However, there is a standard rule that we can follow for converting other fractions to decimals so that the procedure becomes almost automatic. Let us take as an example the fraction $\frac{1}{8}$.

To convert $\frac{1}{8}$ into a decimal we simply divide 8 into 1. We do this by setting up the problem for division and then placing a decimal point to the right of the 1 and then adding as many zeros as we may need to the right of the 1. Now we start by dividing 8 into 1 and since it cannot go, we place a decimal point above

$$\begin{array}{r@{}l} & .125 \\ 8 & \overline{)1.00000} \\ & \underline{8} \\ & 20 \\ & \underline{16} \\ & 40 \\ & \underline{40} \end{array}$$

Fig. 19. Converting 1/8 to a decimal.

the line immediately above the decimal point to the right of the 1 and now divide 8 into 10 as shown in Fig. 19. 8 will go into 10 once so we place a 1 to the right of the decimal point and place an 8 beneath the 10. Subtracting 8 from 10 we get 2, so we bring down the next 0 and now divide 8 into 20. It will go twice so we place the 2 in our answer to the right of the 1 and multiplying 8 by 2 we get 16 which we place beneath the 20. Now subtracting 16 from 20 gives us 4 and we bring down the next 0. 8 will go into 40 five times so we place a 5 to the right of the 2 in our answer and since 5 times 8 is 40 we place this 40 beneath the other 40 and subtracting, our remainder is 0 so the decimal equivalent of $\frac{1}{8}$ is .125.

To convert $\frac{5}{8}$ to a decimal we proceed in exactly the same manner. We set down the division as shown in Fig. 20 and divide 8 into 5 and get as our answer .625.

$$\begin{array}{r@{}l} & .625 \\ 8 & \overline{)5.000} \\ & \underline{4\,8} \\ & 20 \\ & \underline{16} \\ & 40 \\ & \underline{40} \end{array}$$

Fig. 20. Converting 5/8 to a decimal.

Any fraction can be converted to a decimal by following this simple procedure. However, not all fractions will work out to an even value. Sometimes you will get a number in the answer or a combination of numbers that will repeat indefinitely. In this case you simply carry out the division as far as necessary. How far you will actually have to carry it out depends upon what accuracy you want in your answer. If you are dealing with money, there would not be much point in carrying the division past two decimal places because the third decimal is less than a cent and a cent is the smallest denomination of money we have.

$$\begin{array}{r@{}l} & .3333 \\ 3 & \overline{)1.00000} \\ & \underline{9} \\ & 10 \\ & \underline{9} \\ & 10 \\ & \underline{9} \\ & 10 \\ & \underline{9} \\ & 1 \end{array}$$

Fig. 21. Converting 1/3 to a decimal produces a repeating 3. No matter how far we carry the division we will always have the remainder of 1 in this problem.

An example of a common fraction that cannot be converted to an exact decimal value is $\frac{1}{3}$. Fig. 21 shows the conversion of $\frac{1}{3}$ to a decimal. We have shown four decimal places and you will notice that no matter how far we carry the division we will always have a remainder of 1 and the next figure to the right will always be a 3. If we wanted to express the fraction $\frac{1}{3}$ as a decimal to 3

```
      .6666
   3/2.0000
     1 8
     ---
       20
       18
       --
        20
        18
        --
         20
         18
         --
          2
```

Fig. 22. Converting 2/3 to a decimal; to three decimal places, 2/3=.667.

places we would write it as .333

When we try to convert $\frac{2}{3}$ to a decimal we run up against a repeating 6 as shown in Fig. 22. Here again we have to decide how many figures we want and then round off our answer. If we wanted to express $\frac{2}{3}$ as a decimal to three decimal places we would write it as .667. Notice that we changed the digit in the third decimal place from a 6 to a 7. The rule for rounding off decimals in this way is that if the next number to the right is more than 5 we add 1. If it is less than 5 we leave the decimal figure as it is. If the next digit to the right should happen to be a 5 then we add 1 if it will make the last number an even number. If the last digit is already an even number we do not add 1. For example, to express the decimal .7635 to three decimal places, since the 3 is an odd number, adding 1 will make it an even number so we would round that off as .764. On the other hand, to express the decimal .8665 to three decimal places, since the third digit is a 6 which is already an even number, we simply drop the 5 and write the decimal as .866

```
        .0625
    16/1.0000
        96
        --
         40
         32
         --
          80
          80
          --
```

Fig. 23. Converting 1/16 to a decimal.

Another example of converting a fraction to a decimal is shown in Fig. 23. Here we have converted $\frac{1}{16}$ to a decimal. Notice that in the first division when we try to divide 16 into 10 it will not go so we place a 0 to the right of the decimal point. Then we try to divide 16 into 100 and it will go 6 times. 6 sixes are 96 which we subtract from 100 to give us a 4. Now we bring down another 0 and 16 into 40 goes twice. 2 × 16 are 32 and subtracting we get 8. Bringing down another 0 we get 80, and 16 goes into 80, 5 times. Thus the decimal equivalent of $\frac{1}{16}$ is .0625. You will run into this situation quite frequently in converting small fractions to decimals, however, do not forget, if the denominator of the fraction will not go into 10, we must place a 0 to the right of the decimal point. If the denominator of the fraction is so large it will not go into 100 then you have to put two zeros to the right of the decimal point and try to divide it into a thousand etc.

Now to get practice converting fractions to decimals, convert the following fractions to decimals. If a fraction does not convert evenly to a decimal, round your answer off correctly to four decimal places. You will find the answers in the back of the book so you can check your results.

SELF-TEST QUESTIONS

81. $\frac{5}{16}$

82. $\frac{7}{8}$

83. $\frac{1}{6}$

84. $\frac{5}{7}$

85. $\frac{13}{16}$

ADDITION AND SUBTRACTION OF DECIMALS

The operations of addition and subtraction of numbers involving decimals are precisely the same as those involving whole numbers. In setting up the problems, the decimal points must be all placed in a vertical line and the decimal point in the sum or difference will be in that same line. Here are several examples:

$$\begin{array}{lr}
\text{ADD} & 123.45 \\
 & 23.41 \\
 & 1745.00 \\
 & 1.12 \\
 & .03 \\
\hline
 & 1893.01
\end{array}$$

$$\begin{array}{lr}
\text{From} & 985.00 \\
\text{Subtract} & 27.43 \\
\hline
 & 957.57
\end{array}$$

For practice, try the following:

$$\begin{array}{lr}
\text{(1) ADD} & 2543.67 \\
 & 100.24 \\
 & 78.29 \\
 & 2.27 \\
 & .09 \\
\hline
\end{array}$$

$$\begin{array}{lr}
\text{(2) From} & 768.08 \\
\text{Subtract} & 129.29
\end{array}$$

Answers: (1) 2724.56 (2) 638.79.

MULTIPLYING DECIMALS

Multiplication of decimal numbers is exactly the same as multiplication of whole numbers except that we need a rule for determining the position of the decimal point in the product. The rule is that we count the number of decimal places in each factor. Then, starting at the right of the product we count off the same number of decimal places to the left as the sum of the number of places in the two factors. For example, in the multiplication

$$232.7 \times 4.89$$

there is one decimal place in the number 232.7 and two decimal places in the number 4.89 and therefore in our answer we will count off three decimal places to the left starting at the right of the product. The multiplication is shown in Fig. 24 and notice that we have a total of 3 decimal places in our answer.

$$\begin{array}{r}
232.7 \\
4.89 \\
\hline
20943 \\
18616 \\
9308 \\
\hline
1137.903
\end{array}$$

Fig. 24. There are three decimal places in the factors and therefore there must be three places in the product.

We follow this rule for placing the decimal point at all times even if it means adding several zeros in our answer. For example, if we find the product of

$$.1273 \times .0032$$

we will get as our product 40736 as shown in Fig. 25. However, there are four decimal places in the number .1273 and four decimal places in the number .0032. Therefore, there must be eight decimal places in our answer. Starting at the right of the product and counting to the left, we find that there are only five digits in our answer and therefore we must add three zeros to the left of the 4 before placing the decimal point so that our answer becomes .00040736.

.1273	4 decimal places
.0032	4 decimal places
2546	8 decimal places
3819	
40736	5 digits
.00040736	8 decimal places

Fig. 25. We must add three zeros to get the required eight decimal places.

DIVIDING DECIMALS

It is no more difficult to divide numbers involving decimals than it is to divide whole numbers, if we remember a few simple facts. You will remember that a division problem is really a fraction. In other words, 1000 ÷ 18 can be written as $\frac{1000}{18}$

You will also remember that in a fraction you can multiply the numerator and the denominator by the same number without changing the value of the fraction.

In division involving decimals, if the divisor has a decimal in it we get rid of the decimal by moving the decimal point to the right. If we move the decimal point one place to the right. This is the equivalent of multiplying the divisor by 10 so we must multiply the dividend by 10 also. We do this by moving the decimal point one place to the right also. For example, in the problem 42.97 ÷ 4.8, we can get rid of the decimal in the divisor by moving it one place to the right and at the same time moving the decimal point in the dividend one place to the right so that our problem then becomes 429.7 ÷ 48.

Sometimes in order to move the decimal point to the right in the dividend we have to add a 0. For example, in the problem 634 ÷ 82.7, to get rid of the decimal point in the divisor we move the decimal point one place to the right and the divisor becomes 827. We must move the decimal point one place to the right in the dividend also and to do this we add a 0 so that the dividend becomes 6340.

When performing a division involving decimals we must keep track of the decimal point. This is done by placing the decimal point in the quotient immediately above the decimal point in the dividend. For example, in the problem 207.09 ÷ 3.9, the first thing we do is move the decimal point one place to the right to get rid of the decimal in the divisor. Then we proceed with the divisor as follows:

$$\begin{array}{r} 53.1 \\ 39\overline{)2070.9} \\ \underline{195} \\ 120 \\ \underline{117} \\ 39 \\ \underline{39} \end{array}$$

Notice that the decimal point in the quotient is placed immediately above the decimal point in the dividend and the first two digits in the quotient were obtained before we used the decimal in the quotient. This means that the 5 and the 3 to the left of the decimal point and the 1 which was obtained using the .9 from the dividend obtained from the right of the decimal point.

Now to get practice adding, multiplying, dividing and subtracting with decimals do the following problems. Be sure that you do your arithmetic carefully and watch the decimal point to be sure you have it in the right place. Check your answers with the answers given in the back of the book.

SELF-TEST QUESTIONS

86. Add
1.34
26.2
8.41
91.74

87. Add 8.33 + 92.1 + 17.41 + 6.3

88. Subtract
91.31
−80.94

89. Subtract 137.42 - 43.8

90. 137.6 × 4.88
91 .43 × .0061
92. 108.33 ÷ 2.3
93. 45.227 ÷ .049
94. .01887 ÷ .051
95. .00173 × 21

MULTIPLYING AND DIVIDING BY TEN

One of the greatest advantages of the decimal system is that multiplication or division by 10,100, or 1000, or any power of ten can be accomplished by simply moving the decimal point as many places to the right (in multiplication) or left (in division) as there are zeros in the particular power of ten. Thus, to multiply a number like 2.35 by 1000, all we have to do is move the decimal point three places to the right, filling in the vacant spaces with zeros to get 2350.

Similarly, to divide by any power of ten requires only that we move the point to the left. Thus, 3500 ÷ 1000 = 3.5.

You will remember that the basic electric units - ampere, volt, farad, cycle, henry, watt, etc. -- are sometimes too large for convenient handling in electronics. In other cases they are much too small. So a set of five prefixes for measurement are used to remedy these situations. These are:

		Units
M	MEGA	1,000,000
k	KILO	1000
m	MILLI	.001
µ	MICRO	.000,001
p	PICO	.000,000,000,001

Pico = µµ or micro-micro.

These units help us by making it possible to express electrical terms in more convenient figures. For example, a radio station in the standard broadcast band might operate on a frequency of 1,470,000 cycles. By moving the decimal point three places to the left, we can convert this frequency in cycles to a frequency in kilocycles. The frequency in kilocycles would be 1,470 kilocycles. If we wanted to go a step further, we could move the decimal point six places to the left instead of 3 places and convert from cycles to megacycles. In this case the frequency would be 1.470 megacycles. Since a kilocycle equals a thousand cycles and a megacycle equals a million cycles it follows that a megacycle equals a thousand kilocycles. Therefore, we can convert from kilocycles to megacycles by moving the decimal point three places to the left. The terms milli, micro and pico are used to express values smaller than one. Thus, to change a current of 1 amp to milliamps, we would move the decimal point three places to the right so that 1 amp = 1000 milliamps. If we had a current .047 amperes, we would convert this to milliamperes by moving the decimal point three places to the right and the current would then be 47 milliamperes. If the current was .000047 amperes, we could convert this to milliamperes again by moving the decimal point three places to the right and the current would be .047 milliamperes. If instead of converting to milliamperes we converted to micro-amperes, we would move the decimal point six places to the right, in which case the current would be 47 micro-amperes. To convert from units such as farads to picofarads, we move the decimal point twelve places to the right. This term has recently come into use and previously was referred to as micro-micro. You will probably see both terms used; you should remember that they mean the same thing. To summarize, to convert from a unit to a larger value we move the decimal place to the left. To convert from units to kilo you move three places to the left and to convert from units to megaunits move it six places to the left. To convert from kilo units to mega units move it three places to the left. It follows that if you are given a value in megohms and you want to convert to ohms, you would move the decimal point six places to the right and if you were given the value in kilohms and you wanted to convert to ohms, you would move the decimal point three places to the right. Thus, in a resistor that had a value of 4.7 megohms, to convert to ohms, you move the decimal point six places to the right and get 4,700,000 ohms. If you had a resistance of 4700 ohms and wanted to convert this to kilohms, you would move the decimal point three places to the left and get 4.7K (kilohms).

From	⟶	To
MEGA	3 places	KILO
KILO	3 places	UNIT
UNIT	3 places	MILLI
MILLI	3 places	MICRO
MICRO	3 places	NANO
NANO	3 places	MICRO-MICRO
MICRO	6 places	MICRO-MICRO
To	⟵	From
PICO	equals	MICRO-MICRO

Fig. 26. Electrical unit conversion table.

A chart which shows which way to move the decimal point and how far to move it to convert if from one unit to another is shown in Fig. 26. After you have used the chart a few times it will become second nature and you will find it comparatively easy to convert from one unit to another.

Remember that when you move the decimal point and there are spaces not filled by numbers, they must be filled by zeros. Now to get practice converting from one unit to another do the following problems:

a. 2.3 kilohms to ohms
b. 437,000 ohms to kilohms
c. .023 megohms to ohms
d. 1.5 amperes to milliamperes
e. 13,000 microamperes to amperes
f. 3 kilovolts to microvolts

g. 1.28 megacycles to kilocycles
h. 4,000 cycles to megacycles
i. 1690 kilocycles to megacycles
j. 3000 microamperes to amperes

Answers

a. 2,300 ohms
b. 437 kilohms
c. 23,000 ohms
d. 1500 ma
e. .013 amperes
f. 3,000,000,000 μv
g. 1280 kc
h. .004 mc
i. 1.69 mc
j. .003 amps

PERCENTAGE

It is very expensive to make any electronic part to an exact value. Fortunately, considerable tolerance is permissible in most electronic circuits so that the components used in it do not have to be made to an exact value. Parts usually have a certain tolerance and this tolerance is expressed as a percentage of the rated or required value.

Percentage is a fractional part expressed in hundredths. In other words, 1% is $\frac{1}{100}$, 2% is $\frac{2}{100}$ and 10% is $\frac{10}{100}$. We normally use the symbol % to stand for the word percent. Thus 5 percent is written 5%. This means $\frac{5}{100}$.

If we say that a resistor has a tolerance of 10%, what we mean is that its actual measured resistance will be within 10% of the value it is supposed to be. In other words, if a resistor is supposed to be a 1,000 ohm resistor and it has a tolerance of 10%, 10% of 1000 is

$$\frac{10}{100} \times 1000 = 100 \text{ ohms}$$

This means that the resistor is within 100 ohms of 1000 ohms. The resistor might have a value as low as 900 ohms or as high as 1100 ohms. In other words, the resistance of the resistor will fall somewhere between 900 ohms and 1100 ohms - it is rare that the value would fall on the exact value of 1000 ohms.

Most resistors used in communications and electronics equipment have tolerances of 5% or 10%. If you want to find an exact range of resistance that a resistor might have, you find how much it might vary from its value by determining the percentage variation from its rated value. If the resistor is a 5% resistor multiply the value of the resistor by 5 over 100 to get the amount it could vary from its rated value and if it is a 10% resistor, multiply the value by 10 over 100. For example, a 470 ohm 5% resistor may have a tolerance of $\frac{5}{100} \times 470 = 23.5$ ohms. This means its value will lie somewhere between 470 - 23.5 ohms and 470 + 23.5 ohms.

The same value resistor that has a 10% tolerance could vary by as much as

$$\frac{10}{100} \times 470 = 47 \text{ ohms}$$

Therefore, it might have a value anywhere between 470 - 47 and 470 + 47 ohms.

In accurate measuring equipment, resistors having a tolerance of 1% or $\frac{1}{2}$ of 1 % are frequently encountered. If you want to find how much a 1% resistor can vary from its rated value, you multiply 1 over 100 times the value of the resistor. If you want to find how much a one half percent resistor varies, then multiply $\frac{1}{2}$ over 100 times its rated value or $\frac{1}{200}$ times its rated value to find how much the one half percent resistor could vary. Then to get the limits of the resistor, you subtract the variation to find how low the resistance can actually be and then you add the variation to find out how high the resistance can actually be.

Sometimes you know the value by which a part varies from its rated value and you want to find what percentage this is of the rated value. To find the percent that one number is to the second number, divide the first number by the second and multiply the quotient by 100. In other words, if you had a 600 ohm resistor and found that it actually measured 650 ohms and you wanted to find what percentage the resistor was of its rated value you would subtract 600 from 650. In other words, the resistor was 50 ohms over its rated value. To convert this to percentage you set the problem up as

$$\frac{50}{600} \times 100 = 8.33\%$$

Since percentage is a fraction of 100 we can easily convert percentage to its decimal number. For example, 40% means $\frac{40}{100}$

To divide 40 by 100 we move the decimal point two places to the left.

$$\text{Thus } 40\% = \frac{40}{100} = .40$$

$$\text{Similarly, } 12\% = \frac{12}{100} = .12$$

$$6\% = \frac{6}{100} = .06$$

You will find it useful to be able to find the given percent of a number. For example, what number is 40% of 350? To find this number we convert 40% to a decimal and then multiply 350 by the decimal.

$$40\% \text{ of } 350 = 350 \times \frac{40}{100} =$$
$$350 \times .40 = 140$$

To get practice doing percent problems you should do the following ten problems. If you find that you are unable to do one particular type, be sure to refer to the model solution in the back of the book to see how the problem is worked and then go back and work the other problems of the same type. Percentage is useful not only in electronics, but in many other activities of every day life.

SELF-TEST QUESTIONS

96. What percent of 105 is 35?
97. What percent of 40 is 8?
98. What is 15% of 60?
99. What is 36% of 4286?
100. A 680 ohm resistance has a tolerance of 10%. What is the lowest value the resistance may have and still be in tolerance?
101. A 2200 ohm, 5% resistor measures 2300 ohms. Is this resistance (a) above, (b) below, (c) within its rated tolerance?
102. A 4.7K-ohm, 10% resistor measures 5200 ohms. Is this resistance (a) above, (b) below, (c) within its rated tolerance?
103. If $\frac{1}{4}$ of the voltage applied to a circuit is dropped across a certain resistor, what percentage of the total voltage does this represent?
104. If $\frac{1}{8}$ of the voltage applied to a circuit is dropped across a certain resistor, what percent-

age of the total voltage does this represent?

105. If the total voltage applied to a circuit is 200 volts and 75% of this voltage is dropped across one resistor, what is the voltage across the resistor?

Solving Circuit Problems

Now that we have reviewed the operations of basic arithmetic let us use these operations to solve some simple dc circuit problems. This will help you in two ways. First, you will get a chance to review some of the facts you learned in this lesson and secondly, you will get a chance to practice applying your arithmetic to actual electronic circuits. This will help you to better understand how these circuits work.

Earlier in this lesson you did a number of problems involving Ohm's Law. We won't do any more examples involving simple applications of Ohm's Law at this time. If you have forgotten the three forms of Ohm's Law, be sure to memorize them again. Remember the three forms are:

$$I = E \div R$$
$$R = E \div I$$
$$E = I \times R$$

You can use Ohm's Law to solve many circuit problems. If you know the voltage and the resistance in the circuit, you can use the formula $I = E \div R$ to find the current. If you know the voltage and the current in a circuit, you can use the formula $R = E \div I$ to find the resistance and if you know the current and the resistance in the circuit, you can use the formula $E = I \times R$ to find the voltage. Remember, if you know any two of the quantities - resistance, current or voltage - you can use the appropriate form of Ohm's Law to find the other quantity.

Remember to give your answer in the proper units. If you are finding the voltage in the circuit, give your answer in volts; if you are finding the current in the circuit, give the answer in amps, and if you are finding the resistance in the circuit, give the answer in ohms. Simply giving a numerical answer without the correct units after it is unsatisfactory.

Remember also that to use Ohm's Law you must have the voltage in volts, the current in amps, and the resistance in ohms. If you are given the current in milliamperes, you must change it to amperes to use Ohm's Law. Similarly, if the voltage is given in millivolts or kilovolts, change it to volts and if the resistance is given in megohms or kilohms, change it to ohms.

In your regular lesson text you learned the power formulas that let you find the power consumed in watts. These formulas are:

$$P = E \times I$$
$$I = P \div E$$
$$E = P \div I$$

Using these formulas, if you know any two of the quantities, power, voltage or current, you can find the other.

For example, find the power in a

circuit if the voltage is 150 volts and the current is 3 amps. Using the formula $P = E \times I$ and substituting for E and I we get:

$$\begin{aligned} P &= E \times I \\ &= 150 \times 3 \\ &= 450 \text{ watts} \end{aligned}$$

If in another problem you are given that the power in a circuit is 660 watts and the voltage is 110 volts, you can find the current in the circuit using the formula $I = P \div E$. For example:

$$\begin{aligned} I &= P \div E \\ &= 660 \div 110 = 6 \text{ amps} \end{aligned}$$

If you are given that the power in the circuit is 800 watts and the current is 2.5 amps, you can find the voltage using the formula $E = P \div I$. You proceed as follows:

$$\begin{aligned} E &= P \div I \\ &= 800 \div 2.5 \\ &= 320 \text{ volts} \end{aligned}$$

There is another formula for power when we know the value of current and resistance, $P = I^2R$. I^2 is equal to $I \times I$. We would use this formula in examples where current and resistance are given and we want to find power. For example, if the current in the circuit is 3 amperes and the resistance in the circuit is 15 ohms, we can find the power dissipated in the circuit.

$$\begin{aligned} P &= I^2R \\ &= 3 \times 3 \times 15 \\ &= 135 \text{ watts} \end{aligned}$$

We can also rearrange this formula to get $I^2 = P \div R$ or $R = P \div I^2$ These two forms are also useful in solving certain problems. For example, if the power in a circuit is 400 watts and the resistance in the circuit is 100 ohms, we can find the current flowing in the circuit using the formula:

$$\begin{aligned} I^2 &= P \div R \\ &= 400 \div 100 \\ &= 4 \end{aligned}$$

This gives us the value of I^2 or $I \times I$. To get the value of I we need a number that when multiplied by itself will give us four. Obviously the answer is 2 and therefore the current is 2 amps. 2 is called the square root of 4. In a later lesson you will learn how to find the square root of a number, but for the present the only problems we will have you do involving square roots will be simple numbers which you will be able to recognize readily. For example, the square root of 4 is 2, the square root of 9 is 3, the square root of 16 is 4, the square root of 25 is 5 etc.

Another version of the power formula that is useful is $P = E^2 \div R$. We use this formula when we know the voltage and the resistance in the circuit. To find the power in the circuit, we divide the voltage squared, which is equal to $E \times E$, by the resistance and this will give us the power in watts. We can also rearrange this formula into the form $E^2 = P \times R$ and $R = E^2 \div P$ and use it to find the voltage in the first case when the power and resistance are known and the resistance in the second case when the voltage and power are known. We will not give any examples in the use of these formulas because they are exactly the same as the other power formulas.

You already learned how to find the resistance of resistors in series, but sometimes you have to find the value of resistors in parallel. The total resistance of two resistors in parallel can be found using the formula:

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

We would use this formula to find the resistance of two resistors in parallel if we have been given the resistance of the individual resistors. For example, if a 20 ohm resistor and a 30 ohm resistor are connected in parallel, find the resistance of the two resistors in parallel. Substituting these values in the formula:

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$= \frac{20 \times 30}{20 + 30}$$

$$= \frac{600}{50}$$

$$= 12 \text{ ohms}$$

Sometimes you will have a circuit where there are more than two resistors connected in parallel. You can use the same formula for finding the resistance of the parallel combination by finding the resistance in groups. For example, if there are three resistors, find the resistance of two of the resistors in parallel while ignoring the third resistor. When you have found the resistance of two of the resistors in parallel, treat this parallel resistance as a single resistance and find the resistance of it in parallel with the third resistor. If there should happen to be four resistors in parallel, group them into two groups of two each. Find the parallel resistance of each group and then treat each group as a single resistor and then find the parallel resistance of the two groups of resistors.

Now to get practice applying the power formulas, Ohm's Law and the various resistance formulas, do the following problems. You will find many of the problems are very similar to many of the problems you have worked in this lesson, but the time you will spend on these additional problems will be spent in a very worthwhile way. It will not only help you with the mathematics, but it will also help you remember the various formulas and how to use them - and give you a better understanding of electronics. Also, if you will work these problems, you should have no difficulty doing the lesson questions because they are very similar to the problems in this group.

SELF-TEST QUESTIONS

106. What is the total resistance of a circuit that has a 35-ohm resistor in parallel with a 75-ohm resistor? Round off your answer to the nearest ohm.
107. If we have a voltage of 120 volts applied to a lamp with a resistance of 100Ω, how many watts of power will be consumed?
108. In the circuit shown in Fig. 27, the total resistance of the circuit is 335 ohms. What is the resistance of R_2?
109. If the current flowing through the circuit in Fig. 27 is 6 amps, what is the power in watts?
110. What is the maximum rated current-carrying capacity of a 500-ohm resistor marked: 500 ohms, 2000 watts?
111. If a vacuum tube that has a filament rating of .25 amps at 5 volts is to be operated from a 6-volt battery, what value of series-dropping resistor would we need?

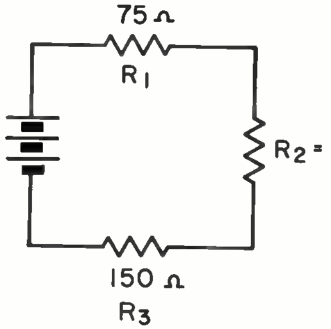


Fig. 27. Circuit for problems 108 and 109.

112. A tube with a filament resistance of 500Ω is designed to operate when 200 milliamperes flow through the filament. What value of resistance must be connected in series with the filament to limit the current to this value if we operate it from 110 volts dc?

113. If resistors of 5, and 15 ohms are connected in parallel, what is the total resistance?

114. If 120 volts dc is applied to a 50Ω resistor connected in series with two resistors of 50Ω in parallel with each other, how much current will flow in the circuit?

115. What is the total resistance of the circuit shown in Fig. 28?

116. A 450Ω resistor has a rated tolerance of ± 10%. When we measure it with an ohmmeter, we find that it actually has a resistance of 410Ω. Is it within its tolerance?

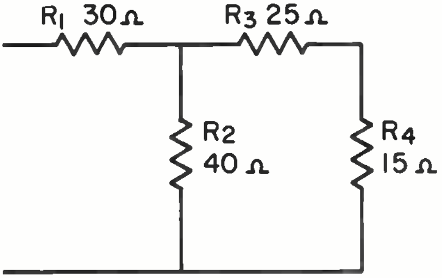


Fig. 29. Circuit for problems 118 and 119.

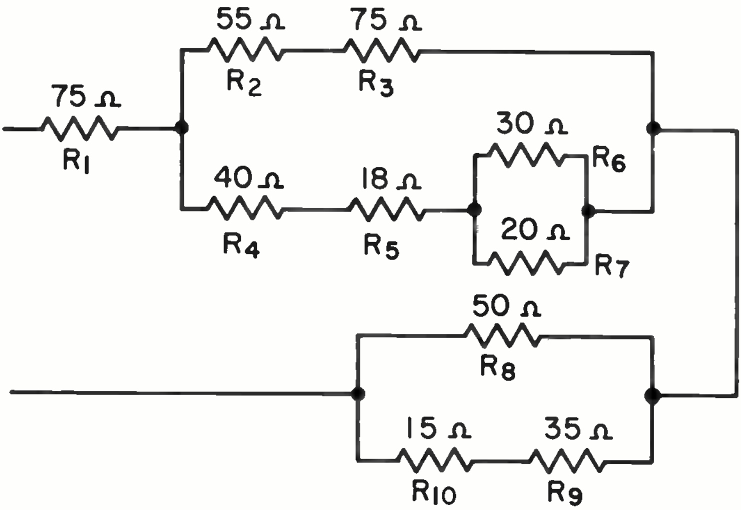


Fig. 28. Circuit for problem 115.

117. Three resistors in series have voltage drops of 36 volts, 24 volts, and 40 volts. What percentage of the total voltage is the 24-volt drop?

118. In the circuit shown in Fig. 29, 450 watts of power are consumed. What is the voltage drop across R_1?

119. How many amperes of current flow through R_4 in the circuit described in Problem 118?

120. A current of 400 milliamps flows through a resistance of 2.2K. What is the voltage drop across the resistor?

Now, as soon as you feel sure that you are ready, work out the answers to the ten questions at the end of the lesson and submit your answers for grading.

Answers To Self-Test Questions

The following solutions to the various problems are to be used after you have tried to work the problems out yourself. Don't look at the answer or the solution until you have made an attempt to do the problem yourself. However, if you do not get the same answer as we do, be sure to go through the solution very carefully to be sure that you find out where you made your mistake. If you work each problem and then check your answer with ours, and if you make any mistakes find out where the mistake is, you should have no difficulty doing the questions at the end of the lesson.

1. The problem here is simply to find the resistance of a number of resistors in series. To do this you simply add the value of the individual resistors. Setting down the values as below we add and get 172 ohms.

$$\begin{array}{r} 68 \\ 31 \\ 9 \\ 17 \\ 21 \\ 7 \\ \underline{19} \\ 172 \end{array}$$

2. In this problem you know the total resistance in the circuit, and you know the resistance of four of the resistors. To find the resistance of the unknown resistor you add the resistance of the four known resistors. We know that this value plus the resistance of the unknown resistor must be equal to 81 ohms. Therefore, to get the correct resistance of the unknown resistor you subtract the resistance of the four resistors in series from the 81 ohms. Putting down the values of the four known resistors to get their total resistance we have:

$$\begin{array}{r} 14 \\ 8 \\ 17 \\ \underline{23} \\ 62 \end{array}$$

Since the total resistance of the four known resistors is 62 ohms, we now subtract 62 from 81 and get 19 ohms; this is the value of the unknown resistor.

$$\begin{array}{r} 81 \\ \underline{-62} \\ 19 \end{array}$$

3. This is simply a series circuit with five resistors connected in series. To find the total resistance we simply add the resistance of the resistors as shown below and get as our answer 511 ohms.

$$\begin{array}{r}127\\97\\9\\219\\\underline{59}\\511\end{array}$$

4. The first step in solving this problem is to determine the resistance of the four known resistors. To do this we put down the values and add as below:

$$\begin{array}{r}216\\318\\91\\\underline{56}\\681\end{array}$$

Thus, the total resistance of the four known resistors is 681 ohms. Since the total resistance in the circuit is 823 ohms, the value of the unknown resistor must be equal to 823 - 681. Thus, we set down the problem subtracting as shown below and get as our answer 142 ohms.

$$\begin{array}{r}823\\\underline{-681}\\142\end{array}$$

5. Here we have a simple application of Ohm's Law. The unknown value is I so we want this on one side of the equation. The known values are $E = 57$ volts and $R = 19$ ohms, so we want these values on the other side of the equation. Thus we use the formula:

$$\begin{aligned}I &= E \div R\\ &= 57 \div 19\\ &= 3 \text{ amps}\end{aligned}$$

6. To solve this problem we want to use Ohm's Law in the form $E = IR$. Here we have the unknown E on one side of the equals sign and the known values $I = 3$ amps and $R = 21$ ohms on the other side of the equals sign. Thus we have:

$$\begin{aligned}E &= IR\\ &= 3 \times 21\\ &= 63 \text{ volts}\end{aligned}$$

7. To do this simple Ohm's Law problem we use, $I = E \div R$ $E = 84$ volts and $R = 28$ ohms so we have:

$$\begin{aligned}I &= E \div R\\ &= 84 \div 28\\ &= 3 \text{ amps}\end{aligned}$$

8. In this problem the known values are E and I, $E = 96$ volts and $I = 4$ amps. We have to find R so we use the formula:

$$\begin{aligned}R &= E \div I\\ &= 96 \div 4\\ &= 24 \text{ ohms}\end{aligned}$$

9. We are given that $I = 5$ amps and $R = 17$ ohms. To find the voltage we use Ohm's Law in the form:

$$\begin{aligned}E &= IR\\ &= 5 \times 17\\ &= 85 \text{ volts}\end{aligned}$$

10. In a problem such as this, where we have the total voltage equal to 32 volts and the total current equal to 2 amps, we can find the total resistance using the formula:

$$\begin{aligned}R &= E \div I\\ &= 32 \div 2\\ &= 16 \text{ ohms}\end{aligned}$$

Since $R_1 = R_2$ and since the two

are in series, $R_1 + R_2 = 16$ ohms and each resistor must be equal to 8 ohms.

11. Using the rules of order, we go through the problem doing the multiplication and division first as we go from left to right. Thus we have:

$25 + 16 \times 3 - 28 \div 7 =$
$25 + 48 - 4 =$
69

12. In this problem we have to do the operations inside the parentheses first and then we go from left to right doing the multiplications and divisions in the order in which they occur. Thus we have:

$5 \times (11 - 8) + 3 \times (7 - 5) \div 2 =$
$5 \times 3 + 3 \times 2 \div 2 =$
$15 + 3 =$
18

13. $4 + (5+2) \times 20 - (10-6) \div (7-5) =$
$4 + 7 \times 20 - 4 \div 2 =$
$4 + 140 - 2 = 142$

14. In this problem you must perform the operation inside the parentheses first, and then we do the operation inside the bracket. Then we go through the problem from left to right doing the multiplication and division in the order in which they occur and then finally go through the problem again from left to right doing the addition and subtraction.

$3 \times 500 \div [2 \times (28 + 22)] + 25 - 6 =$
$3 \times 500 \div [2 \times 50] + 25 - 6 =$
$3 \times 500 \div 100 + 25 - 6 =$
$15 + 25 - 6 = 34$

15. $95 \div (22 - 17) - 6 \times 2 - 3 + 8 =$
$95 \div 5 - 6 \times 2 - 3 + 8 =$
$19 - 12 - 3 + 8 = 12$

16. $\frac{3}{7} + \frac{5}{7} + \frac{6}{7} =$

$$\frac{3+5+6}{7} =$$

$$\frac{14}{7} = 2$$

17. $\frac{1}{2} + \frac{1}{3} + \frac{1}{12} =$

$$\frac{6+4+1}{12} =$$

$$\frac{11}{12}$$

18. $\frac{1}{2} + \frac{1}{3} + \frac{1}{5} =$

$$\frac{15+10+6}{30} =$$

$$\frac{31}{30} = 1\frac{1}{30}$$

19. $\frac{3}{8} + \frac{1}{2} + \frac{3}{4} =$

$$\frac{3+4+6}{8} =$$

$$\frac{13}{8} = 1\frac{5}{8}$$

20. $\frac{3}{4} + \frac{1}{16} + \frac{1}{8} =$

$$\frac{12+1+2}{16}$$

$$= \frac{15}{16}$$

21. $\frac{1}{3} + \frac{1}{7} + \frac{3}{14} =$

$$\frac{14+6+9}{42} =$$

$$\frac{29}{42}$$

22. $\frac{6}{23} + \frac{8}{46} + \frac{19}{69} =$

$$\frac{6}{23} + \frac{4}{23} + \frac{19}{69} =$$

$$\frac{18+12+19}{69} =$$

$$\frac{49}{69}$$

23. $\frac{1}{5} + \frac{2}{9} + \frac{3}{11} =$

$$\frac{99+110+135}{495} =$$

$$\frac{344}{495}$$

24. $\frac{1}{9} + \frac{3}{4} + \frac{1}{8} =$

$$\frac{8+54+9}{72} =$$

$$\frac{71}{72}$$

25. $\frac{7}{25} + \frac{9}{35} + \frac{2}{5} =$

$$\frac{49+45+70}{175} =$$

$$\frac{164}{175}$$

26. $\frac{5}{7} - \frac{3}{7} =$

$$\frac{5-3}{7} =$$

$$\frac{2}{7}$$

27. $\frac{2}{3} - \frac{1}{2} =$

$$\frac{4-3}{6} =$$

$$\frac{1}{6}$$

28. $\frac{7}{10} - \frac{3}{5} =$

$\frac{7 - 6}{10} =$

$\frac{1}{10}$

29. $\frac{8}{9} - \frac{2}{5} =$

$\frac{40 - 18}{45} =$

$\frac{22}{45}$

30. $\frac{3}{4} - \frac{3}{8} =$

$\frac{6 - 3}{8} =$

$\frac{3}{8}$

31. $\frac{25}{27} - \frac{1}{3} =$

$\frac{25 - 9}{27} =$

$\frac{16}{27}$

32. $\frac{3}{4} - \frac{1}{6} - \frac{1}{3} =$

$\frac{9 - 2 - 4}{12} =$

$\frac{3}{12} = \frac{1}{4}$

33. $\frac{7}{8} - \frac{1}{9} - \frac{1}{5} =$

$\frac{315 - 40 - 72}{360} =$

$\frac{203}{360}$

34. $\frac{4}{5} - \frac{3}{25} - \frac{3}{50} =$

$\frac{40 - 6 - 3}{50} =$

$\frac{31}{50}$

35. $\frac{35}{36} - \frac{3}{9} - \frac{1}{4} =$

$\frac{35 - 12 - 9}{36} =$

$\frac{14}{36} = \frac{7}{18}$

36. $1\frac{1}{4} + 2\frac{1}{5} =$

$1 + 2 + \frac{1}{4} + \frac{1}{5} =$

$3 + \frac{5 + 4}{20} =$

$3 + \frac{9}{20} = 3\frac{9}{20}$

37. $2\frac{1}{2} + 3\frac{1}{3} + 1\frac{1}{6} =$

$2 + 3 + 1 + \frac{1}{2} + \frac{1}{3} + \frac{1}{6} =$

$6 + \frac{3 + 2 + 1}{6} =$

$6 + \frac{6}{6} = 6 + 1 = 7$

38. $4\frac{7}{8} - 3\frac{1}{4} =$

$4 - 3 + \frac{7}{8} - \frac{1}{4} =$

$1 + \frac{7 - 2}{8} =$

$1 + \frac{5}{8} = 1\frac{5}{8}$

39. $5\frac{1}{8} - 2\frac{3}{7} =$

$5 - 2 + \frac{1}{8} - \frac{3}{7} =$

$3 + \frac{7 - 24}{56} =$

$2 + \frac{63 - 24}{56} =$

$2 + \frac{39}{56} = 2\frac{39}{56}$

40. $8\frac{1}{9} - 3\frac{2}{7} - 2\frac{2}{3} =$

$8 - 3 - 2 + \frac{1}{9} - \frac{2}{7} - \frac{2}{3} =$

$3 + \frac{1}{9} - \frac{2}{7} - \frac{2}{3} =$

$2 + \frac{10}{9} - \frac{2}{7} - \frac{2}{3} =$

$2 + \frac{70 - 18 - 42}{63} =$

$2 + \frac{10}{63} = 2\frac{10}{63}$

41. $\frac{1}{7} + \frac{8}{9} - \frac{1}{3} =$

$\frac{9 + 56 - 21}{63} =$

$\frac{44}{63}$

42. $\frac{3}{4} - \frac{1}{9} + \frac{3}{18} - \frac{1}{2} =$

$\frac{27 - 4 + 6 - 18}{36} =$

$\frac{33 - 22}{36} = \frac{11}{36}$

43. $4\frac{3}{8} + 1\frac{1}{4} - 2\frac{1}{7} =$

$4 + 1 - 2 + \frac{3}{8} + \frac{1}{4} - \frac{1}{7} =$

$3 + \frac{21 + 14 - 8}{56} =$

$3 + \frac{27}{56} = 3\frac{27}{56}$

44. $1\frac{7}{8} - 3\frac{1}{7} - 1\frac{1}{6} + 8\frac{2}{9} =$

$1 - 3 - 1 + 8 + \frac{7}{8} - \frac{1}{7} - \frac{1}{6} + \frac{2}{9} =$

$5 + \frac{441 - 72 - 84 + 112}{504} =$

$5 + \frac{553 - 156}{504} = 5 + \frac{397}{504} = 5\frac{397}{504}$

45\. $6\frac{1}{3} - 4\frac{3}{4} + \frac{1}{9} - 1\frac{1}{3} =$

$6 - 4 - 1 + \frac{1}{3} - \frac{3}{4} + \frac{1}{9} - \frac{1}{3} =$

$1 + \frac{12 - 27 + 4 - 12}{36} =$

$1 + \frac{16 - 39}{36} =$

$\frac{52 - 39}{36} = \frac{13}{36}$

46\. $\frac{1}{3} \times \frac{1}{4} =$

$\frac{1 \times 1}{3 \times 4} = \frac{1}{12}$

47\. $\frac{1}{7} \times \frac{2}{9} =$

$\frac{1 \times 2}{7 \times 9} = \frac{2}{63}$

48\. $\frac{3}{4} \times \frac{3}{8} =$

$\frac{3 \times 3}{4 \times 8} = \frac{9}{32}$

49\. $\frac{7}{8} \times \frac{4}{7} =$

$\frac{\overset{1}{\cancel{7}} \times 4}{8 \times \underset{1}{\cancel{7}}} = \frac{4}{8} = \frac{1}{2}$

50\. $\frac{5}{13} \times \frac{26}{30} =$

$\frac{\overset{1}{\cancel{5}} \times \overset{2}{\cancel{26}}}{\underset{1}{\cancel{13}} \times \cancel{30}} = \frac{2}{6} = \frac{1}{3}$

51\. $\frac{3}{7} \times \frac{7}{8} \times \frac{2}{3} =$

$\frac{\overset{1}{\cancel{3}} \times \overset{1}{\cancel{7}} \times 2}{\underset{1}{\cancel{7}} \times 8 \times \underset{1}{\cancel{3}}} = \frac{2}{8} = \frac{1}{4}$

52\. $\frac{3}{8} \times \frac{16}{19} \times \frac{19}{21} =$

$\frac{\overset{1}{\cancel{3}} \times \overset{2}{\cancel{16}} \times \overset{1}{\cancel{19}}}{\underset{1}{\cancel{8}} \times \underset{1}{\cancel{19}} \times \underset{7}{\cancel{21}}} = \frac{2}{7}$

53\. $\frac{1}{8} \times \frac{8}{9} \times \frac{9}{23} =$

$\frac{1 \times \overset{1}{\cancel{8}} \times \overset{1}{\cancel{9}}}{\underset{1}{\cancel{8}} \times \underset{1}{\cancel{9}} \times 23} = \frac{1}{23}$

54\. $\frac{4}{7} \times \frac{21}{28} \times \frac{7}{9} =$

$\frac{\overset{1}{\cancel{4}} \times \overset{1}{\overset{\cancel{3}}{\cancel{21}}} \times \overset{1}{\cancel{7}}}{\underset{1}{\cancel{7}} \times \underset{1}{\underset{\cancel{7}}{\cancel{28}}} \times \underset{3}{\cancel{9}}} = \frac{1}{3}$

55\. $\frac{18}{20} \times \frac{30}{36} \times \frac{2}{3} =$

$\frac{\overset{1}{\cancel{18}} \times \overset{1}{\overset{\cancel{10}}{\cancel{30}}} \times \overset{1}{\cancel{2}}}{\underset{1}{\underset{\cancel{10}}{\cancel{20}}} \times \underset{2}{\cancel{36}} \times \underset{1}{\cancel{3}}} = \frac{1}{2}$

56\. $\frac{1}{3} ÷ \frac{2}{9} =$

$\frac{1}{\underset{1}{\cancel{3}}} \times \frac{\overset{3}{\cancel{9}}}{2} = \frac{3}{2} = 1\frac{1}{2}$

57\. $\frac{2}{7} ÷ \frac{3}{7} = \frac{2}{\underset{1}{\cancel{7}}} \times \frac{\overset{1}{\cancel{7}}}{3} = \frac{2}{3}$

58\. $\frac{3}{4} ÷ \frac{9}{16} =$

$\frac{\overset{1}{\cancel{3}}}{\underset{1}{\cancel{4}}} \times \frac{\overset{4}{\cancel{16}}}{\underset{3}{\cancel{9}}} = \frac{4}{3} = 1\frac{1}{3}$

59\. $\frac{47}{49} ÷ \frac{1}{7} =$

$\frac{47}{\underset{7}{\cancel{49}}} \times \frac{\overset{1}{\cancel{7}}}{1} = \frac{47}{7} = 6\frac{5}{7}$

60\. $\frac{19}{23} \times \frac{41}{38} =$

$\frac{\overset{1}{\cancel{19}}}{23} \times \frac{41}{\underset{2}{\cancel{38}}} =$

$\frac{41}{46}$

61\. $\frac{2}{7} ÷ \frac{1}{14} ÷ \frac{1}{2} =$

$\frac{2}{\underset{1}{\cancel{7}}} \times \frac{\overset{2}{\cancel{14}}}{1} \times \frac{2}{1} = \frac{8}{1} = 8$

62\. $\frac{1}{9} ÷ \frac{2}{3} ÷ \frac{3}{7} =$

$\frac{1}{9} \times \frac{\overset{1}{\cancel{3}}}{2} \times \frac{7}{\underset{1}{\cancel{3}}} = \frac{7}{18}$

63\. $\frac{2}{11} ÷ \frac{4}{7} ÷ \frac{3}{14} =$

$\frac{\overset{1}{\cancel{2}}}{11} \times \frac{7}{\underset{1}{\underset{\cancel{2}}{\cancel{4}}}} \times \frac{\overset{7}{\cancel{14}}}{3} =$

$\frac{49}{33} = 1\frac{16}{33}$

64\. $\frac{2}{9} ÷ \frac{4}{5} ÷ \frac{5}{8} =$

$\frac{2}{9} \times \frac{\overset{1}{\cancel{5}}}{\underset{1}{\cancel{4}}} \times \frac{\overset{2}{\cancel{8}}}{\underset{1}{\cancel{5}}} = \frac{4}{9}$

65\. $\frac{13}{15} ÷ \frac{2}{5} ÷ \frac{4}{9} =$

$\frac{13}{\underset{1}{\underset{\cancel{3}}{\cancel{15}}}} \times \frac{\overset{1}{\cancel{5}}}{2} \times \frac{\overset{3}{\cancel{9}}}{4} =$

$\frac{39}{8} = 4\frac{7}{8}$

66\. $1\frac{1}{4} \times 2\frac{1}{2} =$

$\frac{5}{4} \times \frac{5}{2} = \frac{25}{8} = 3\frac{1}{8}$

67\. $2\frac{3}{8} \times 4\frac{1}{7} =$

$\frac{19}{8} \times \frac{29}{7} = \frac{551}{56} = 9\frac{47}{56}$

68\. $4\frac{3}{7} \times 5\frac{4}{9} =$

$\frac{31}{\underset{1}{\cancel{7}}} \times \frac{\overset{7}{\cancel{49}}}{9} = \frac{217}{9} = 24\frac{1}{9}$

69\. $6\frac{7}{8} ÷ 2\frac{1}{4} =$

$\frac{55}{8} ÷ \frac{9}{4} =$

$\frac{55}{\underset{2}{\cancel{8}}} \times \frac{\overset{1}{\cancel{4}}}{9} =$

$\frac{55}{18} = 3\frac{1}{18}$

70. $5\frac{1}{8} \div 3\frac{1}{7} =$

$$\frac{41}{8} \div \frac{22}{7} =$$

$$\frac{41}{8} \times \frac{7}{22} = \frac{287}{176} = 1\frac{111}{176}$$

71. $8\frac{2}{9} \div 5\frac{1}{6} =$

$$\frac{74}{9} \div \frac{31}{6}$$

$$\frac{74}{\underset{3}{\cancel{9}}} \times \frac{\overset{2}{\cancel{6}}}{31} = \frac{148}{93} = 1\frac{55}{93}$$

72. $8\frac{1}{9} \times 3\frac{1}{5} \div 9\frac{1}{7} =$

$$\frac{73}{9} \times \frac{16}{5} \div \frac{64}{7} =$$

$$\frac{73}{9} \times \frac{\overset{1}{\cancel{16}}}{5} \times \frac{7}{\underset{4}{\cancel{64}}} =$$

$$\frac{511}{180} = 2\frac{151}{180}$$

73. $6\frac{2}{3} \div 2\frac{2}{9} \times 4\frac{3}{4} =$

$$\frac{20}{3} \div \frac{20}{9} \times \frac{19}{4} =$$

$$\frac{\overset{1}{\cancel{20}}}{\underset{1}{\cancel{3}}} \times \frac{\overset{3}{\cancel{9}}}{\underset{1}{\cancel{20}}} \times \frac{19}{4} = \frac{57}{4} = 14\frac{1}{4}$$

74. $3\frac{1}{4} \div 8\frac{1}{2} \times 2\frac{1}{8} =$

$$\frac{13}{4} \div \frac{17}{2} \times \frac{17}{8} =$$

$$\frac{13}{4} \times \frac{\overset{1}{\cancel{2}}}{\underset{1}{\cancel{17}}} \times \frac{\overset{1}{\cancel{17}}}{\underset{4}{\cancel{8}}} = \frac{13}{16}$$

75. $1\frac{7}{8} \div 6\frac{6}{9} \times 2\frac{1}{2} =$

$$\frac{15}{8} \div \frac{60}{9} \times \frac{5}{2} =$$

$$\frac{\overset{1}{\cancel{15}}}{8} \times \frac{9}{\underset{4}{\cancel{60}}} \times \frac{5}{2} =$$

$$\frac{45}{64}$$

76. $\frac{1}{2} + \frac{1}{4} \times \frac{3}{5} - \frac{1}{10} + \frac{1}{10} \div \frac{3}{5} =$

$$\frac{1}{2} + \frac{3}{20} - \frac{1}{10} + \frac{1}{\underset{2}{\cancel{10}}} \times \frac{\overset{1}{\cancel{5}}}{3} =$$

$$\frac{1}{2} + \frac{3}{20} - \frac{1}{10} + \frac{1}{6} =$$

$$\frac{30 + 9 - 6 + 10}{60} = \frac{43}{60}$$

77. $\frac{1}{2} \div \frac{1}{8} \times \frac{5}{7} - \frac{1}{8} \times \frac{8}{9} \div \frac{1}{3} =$

$$\frac{1}{\underset{1}{\cancel{2}}} \times \frac{\overset{4}{\cancel{8}}}{1} \times \frac{5}{7} - \frac{1}{\cancel{8}} \times \frac{\cancel{8}}{\underset{3}{\cancel{9}}} \times \frac{\overset{1}{\cancel{3}}}{1} =$$

$$\frac{20}{7} - \frac{1}{3} = \frac{60 - 7}{21} = \frac{53}{21} = 2\frac{11}{21}$$

78. $\frac{1}{2} - \frac{1}{4} \times \frac{1}{3} + \frac{1}{2} \div \frac{3}{4} - \frac{1}{6} =$

$$\frac{1}{2} - \frac{1}{12} + \frac{1}{\underset{1}{\cancel{2}}} \times \frac{\overset{2}{\cancel{4}}}{3} - \frac{1}{6} =$$

$$\frac{1}{2} - \frac{1}{12} + \frac{2}{3} - \frac{1}{6} =$$

$$\frac{6 - 1 + 8 - 2}{12} = \frac{11}{12}$$

79. $1\frac{1}{4} + 1\frac{3}{8} \times \frac{3}{8} \div 2\frac{3}{4} - 3 \times \frac{1}{9} \div \frac{3}{4} =$

$$\frac{5}{4} + \frac{\cancel{11}}{8} \times \frac{3}{\underset{2}{\cancel{8}}} \times \frac{\cancel{4}}{\cancel{11}} - \frac{\cancel{3}}{1} \times \frac{1}{9} \times \frac{4}{\cancel{3}} =$$

$$\frac{5}{4} + \frac{3}{16} - \frac{4}{9} =$$

$$\frac{180 + 27 - 64}{144} = \frac{143}{144}$$

80. $\left(\frac{3}{4} + \frac{1}{8}\right) \div \frac{7}{8} - \left(\frac{3}{4} - \frac{1}{8}\right) \times \frac{8}{9} =$

$$\left(\frac{6 + 1}{8}\right) \div \frac{7}{8} - \left(\frac{6 - 1}{8}\right) \times \frac{8}{9} =$$

$$\frac{\cancel{7}}{\cancel{8}} \times \frac{\cancel{8}}{\cancel{7}} - \frac{5}{\cancel{8}} \times \frac{\cancel{8}}{9} =$$

$$1 - \frac{5}{9} = \frac{9 - 5}{9} = \frac{4}{9}$$

81.
$$\begin{array}{r} .3125 \\ 16\overline{)5.00} \\ \underline{4\ 8} \\ 20 \\ \underline{16} \\ 40 \\ \underline{32} \\ 80 \\ \underline{80} \end{array}$$

82.
$$\begin{array}{r} .875 \\ 8\overline{)7.000} \\ \underline{6\ 4} \\ 60 \\ \underline{56} \\ 40 \\ \underline{40} \end{array}$$

83.
$$\begin{array}{r} .16666 \\ 6\overline{)1.00000} \\ \underline{6} \\ 40 \\ \underline{36} \\ 40 \\ \underline{36} \\ 40 \\ \underline{36} \\ 40 \\ \underline{36} \\ 4 \end{array} = .1667$$

84.
$$\begin{array}{r} .71428 \\ 7\overline{)5.0000} \\ \underline{4\ 9} \\ 10 \\ \underline{7} \\ 30 \\ \underline{28} \\ 20 \\ \underline{14} \\ 60 \end{array} = .7143$$

85.
$$\begin{array}{r} .8125 \\ 16\overline{)13.000} \\ \underline{12\ 8} \\ 20 \\ \underline{16} \\ 40 \\ \underline{32} \\ 80 \\ \underline{80} \end{array}$$

86.
$$\begin{array}{r} 1.34 \\ 26.2 \\ 8.41 \\ \underline{91.74} \\ 127.69 \end{array}$$

87.
$$\begin{array}{r} 8.33 \\ 92.1 \\ 17.41 \\ \underline{6.3} \\ 124.14 \end{array}$$

88.
$$\begin{array}{r} 91.31 \\ \underline{-80.94} \\ 10.37 \end{array}$$

89.
$$\begin{array}{r} 137.42 \\ -\ \ 43.8 \\ \hline 93.62 \end{array}$$

90.
$$\begin{array}{rl} 137.6 & \text{1 decimal place} \\ 4.88 & \text{2 decimal places} \\ \hline 110\ 08 & \text{3 decimal places} \\ 1100\ 8 & \\ 5504\ \ \ \ & \\ \hline 671.488 & \text{3 decimal places} \end{array}$$

91.
$$\begin{array}{rl} .43 & \text{2 decimal places} \\ .0061 & \underline{\text{4 decimal places}} \\ \hline 43 & \text{6 decimal places} \\ 258\ \ & \\ \hline .002623 & \text{6 decimal places} \end{array}$$

92. 2.3/108.33

$$\begin{array}{r} 47.1 \\ 23\overline{)1083.3} \\ \underline{92\ \ \ \ } \\ 163\ \ \\ \underline{161\ \ } \\ 23 \\ \underline{23} \end{array}$$

93. .049/45.227

$$\begin{array}{r} 923 \\ 49\overline{)45227} \\ \underline{441\ \ } \\ 112\ \\ \underline{98\ } \\ 147 \\ \underline{147} \end{array}$$

94. .051/.01887

$$\begin{array}{r} .37 \\ 51\overline{)18.87} \\ \underline{15\ 3\ } \\ 3\ 57 \\ \underline{3\ 57} \end{array}$$

95.
$$\begin{array}{rl} .00173 & \text{5 decimal places} \\ 21 & \underline{\text{0 decimal places}} \\ \hline 173 & \text{5 decimal places} \\ 346\ & \\ \hline .03633 & \text{5 decimal places} \end{array}$$

96. $\frac{\overset{1}{\cancel{35}}}{\underset{3}{\cancel{105}}} \times 100 = 33\frac{1}{3}\%$

97. $\frac{\overset{1}{\cancel{8}}}{\underset{\substack{\cancel{5}\\1}}{\cancel{40}}} \times \overset{20}{\cancel{100}} = 20\%$

98. $\frac{\overset{3}{\cancel{15}}}{\underset{\substack{\cancel{20}\\1}}{\cancel{100}}} \times \overset{3}{\cancel{60}} = 9$

99. $\frac{36}{100} \times 4286 = 1542.96$

100. 10% of 680 =

$\frac{10}{100} \times 680 = 68$ ohms

∴ Lowest value = 680 - 68 = 612 ohms.

101. 5% of 2200 =

$\frac{5}{100} \times 2200 = 110$ ohms.

2200 + 110 = 2310 ohms.

∴ 2300 ohms is within its rated tolerance.

102. 10% of 4.7 K =

$\frac{10}{100} \times 4700 = 470$ ohms

4700 + 470 = 5170 ohms.

5200 is greater than 5170

∴ resistor is above its rated tolerance

103. $\frac{1}{4} \times 100 = 25\%$

104. $\frac{1}{8} \times 100 = 12.5\%$

105. 75% of 200 volts =

$$\frac{75}{100} \times 200 = 150 \text{ volts}$$

106. $R_t = \frac{R_1 \times R_2}{R_1 + R_2}$

$$= \frac{35 \times 75}{35 + 75}$$

$$= \frac{2625}{110}$$

$$= 23.8 \text{ ohms}$$

$$= 24 \text{ ohms}$$

107. $P = E^2 \div R = \frac{12\cancel{0} \times 120}{10\cancel{0}}$

$$= \frac{12 \times 12\cancel{0}}{1\cancel{0}} = \frac{12 \times 12}{1}$$

$$= \frac{144}{1} = 144 \text{ watts}$$

108. $R_1 + R_2 = 75 + 150 = 225\,\Omega$
$R_t = 335\,\Omega$
$\therefore R_2 = 335 - 225 = 110\,\Omega$

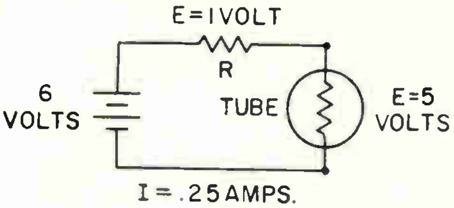
109. $P = 1^2 \times R$
$= 6 \times 6 \times 335$
$= 12{,}060$ watts

110. $P = 2000$ watts $R = 500\,\Omega$
$I^2 = P \div R$

$$= \frac{2000}{500} = 4$$

If $I \times I = 4$, then $I = 2$ amps.

111. In this problem you have 2 resistors in series. One resistor is the tube filament which has a voltage drop of 5 volts across it. The other resistor must use up or drop the extra voltage which is the difference between the battery voltage and the tube filament voltage in this case. 6-5 = 1 volt. Therefore we have the circuit:



We have E across R = 1 volt, I = .25 amps

$$\therefore R = \frac{E}{I} = \frac{1}{.25} = 4 \text{ ohms}$$

112. The current through the tube filament = 200 milliamps

200 milliamps = .2 amps.

resistance of filament = 500 ohms.

$\therefore$ voltage across filament

$E = I \times R$
$= .2 \times 500$
$= 100$ volts

$\therefore$ series resistor must drop 110-100 = 10 volts

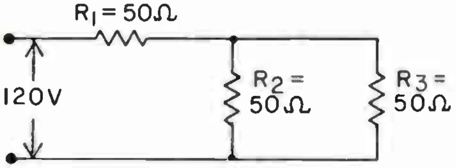
$$\therefore R = \frac{10}{.2} = 50 \text{ ohms.}$$

113. $R_t = \frac{R_1 \times R_2}{R_1 + R_2}$

$$= \frac{5 \times 15}{5 + 15}$$

$$= \frac{75}{20} = 3.75 \text{ ohms}$$

114. The circuit we have in this problem is:



First we find the value of R^2 and R^3 in parallel:

$$R_t = \frac{R_2 \times R_3}{R_2 + R_3}$$

$$= \frac{50 \times 50}{50 + 50} = \frac{2500}{100} = 25$$

∴ total series resistance is R_1 in series with 25 Ω

$50 + 25 = 75\Omega$

Now we know $E = 120V$ and $R = 75\Omega$ so we can find I:

$$I = \frac{E}{R}$$

$$= \frac{120}{75} = 1.6 \text{ amps}$$

115. At first glance, this problem might look difficult, but it is just a matter of solving it a step at a time.

First we find the value of $R_6 \times R_7$ in parallel:

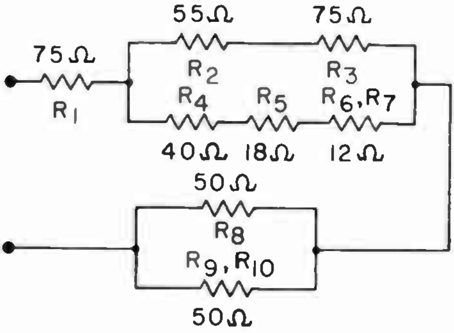
$$R_t = \frac{R_6 \times R_7}{R_6 + R_7}$$

$$= \frac{30 \times 20}{30 + 20} = \frac{600}{50} = 12\Omega$$

Next we find the value of R_9 and R_{10} in series:

$R_9 + R_{10} = 35 + 15 = 50$

Now we can redraw the circuit and substitute for R_6 and R_7 and for R_9 and R_{10}:



Now we find R_2 and R_3 in series:

$R_2 + R_3 = 55 + 75 = 130\Omega$

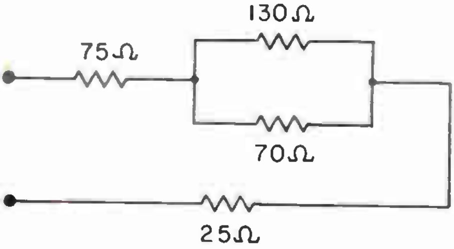
and R_4, R_5 and $R_6 - R_7$ in series:

$40 + 18 + 12 = 70\Omega$

Also we find R_8 in parallel with $R_9 - R_{10}$:

$$R_t = \frac{50 \times 50}{50 + 50} = \frac{2500}{100} = 25\Omega$$

Now we can redraw our circuit and substitute this value:



Now we find the value of 130Ω in parallel with 70Ω:

$$R_t = \frac{130 \times 70}{130 + 70} = \frac{9100}{200} = 45.5\Omega$$

Now we have 75 + 45.5 + 25 = 145.5

116. 10% of 450Ω =

$$\frac{10}{100} \times 450 = 45\Omega$$

$\therefore$ 450-45 = 405Ω is the lowest value in tolerance

$\therefore$ 410Ω is in tolerance

117. Total voltage = 36 + 24 + 40 = 100 volts.

$\therefore$ 24 volts $= \frac{24}{100} \times 100 = 24\%$

118. The first step in solving this problem is to find the total R.

$R_3 + R_4 = 25 + 15 = 40\Omega$

$\therefore$ $R_3 + R_4$ in parallel with R_2 =

$$\frac{40 \times 40}{40 + 40} = \frac{1600}{80} = 20\Omega$$

$\therefore$ R_1 + parallel combination = 30 + 20 = 50Ω

power = 450 watts

$$\therefore \quad I^2 = \frac{450}{50} = 9$$

$\therefore$ I × I = 9 and I = 3 amps.

$\therefore$ Voltage drop across R_1

E = I × R = 3 × 30 = 90 volts

119. Total current = 3 amps. Part flows through R_2 and part through R_3 and R_4.

Since $R_2 = 40\Omega$ and $R_3 + R_4 = 40\Omega$

current flowing in each branch will be equal

$$\therefore \quad I_{R4} = \frac{3}{2} = 1.5 \text{ amps}$$

120. I = 400 milliamps = .4 amps
R = 2.2K = 2200 ohms.
$\therefore$ E = I × R = .4 × 2200 = 880 volts.

Lesson Questions

Be sure to number your Answer Sheet X105.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grades as soon as possible, so they mail their answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable. However, don't hold your answers too long; you may lose them. Don't hold answers to more than two sets of lessons at any time, or you may run out of lessons before new ones can reach you.

1. A supply voltage of 120 volts is applied to three resistors in series. One resistor has a drop of 55 volts, another a drop of 30 volts. What is the voltage drop across the third resistor?

2. A 750-ohm resistor has a rated tolerance of ±5%. When it is measured with an accurate ohmmeter, we find that the meter reads 697 ohms. Is the resistor (a) above, (b) below, (c) within its rated tolerance?

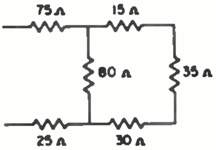
3. If 640 watts are consumed in a circuit with a total resistance of 160 ohms, how much current will flow in the circuit?

4. A current of 200 milliamps flows through a resistance of 1.6K. What is the voltage drop across the resistor?

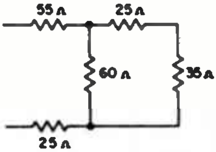
5. Find the answer to the problem 5 + 60 X 3 ÷ 4 – 6.

6. If 1/16th of the voltage applied to a circuit is dropped across a certain resistor, exactly what percentage of the total voltage does this represent?

7. What is the total resistance of the circuit shown at the right?



8. If 440 volts is applied to the circuit at the right, how much voltage will be dropped across the 35Ω resistor?



9. If a vacuum tube filament has a resistance of 20 ohms, and is rated at 250 milliamps, how much voltage should we apply so that it will draw its rated current?

10. The power consumed in a circuit is 160 watts. The voltage applied is 80 volts. What is the resistance of the circuit?

LEARNING NEVER ENDS

More and more it becomes evident that learning is a continuous process--that it is impossible to break the habit of studying without slipping backward. Look around you at all the marvelous developments of the last twenty years. You have the advantage of having "grown up" with them--yet there are probably many things you wish you knew more about. Then, consider what can happen in the years ahead if you do not keep abreast of the stream of new things that are bound to come!

Your NRI Course is preparing you for the problems of today and tomorrow, but what about the day after tomorrow? In five or ten years, will you still be up-to-date? Yes, if you plan your future. Resolve now--that you WILL keep up. You have the fundamentals; keep them fresh in your mind by constantly reviewing. Read and study technical literature and textbooks; join in discussion groups and listen to lectures; take advantage of every possible educational opportunity. Then, and only then, can you face the future unafraid, no matter what technical developments the future may hold.

Innovation in learning
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Continuing Education School

ACHIEVEMENT THROUGH ELECTRONICS

AC CIRCUIT CALCULATIONS

REFERENCE TEXT X109

NATIONAL RADIO INSTITUTE • WASHINGTON, D. C.

AC CIRCUIT CALCULATIONS

REFERENCE TEXT X109

STUDY SCHEDULE

☐ 1. **Introduction** . . . . **Pages 1 - 2**

A quick look at the basic operations you will study in this lesson as they apply to ac circuit problems.

☐ 2. **Square Roots** . . . . **Pages 3 - 11**

Here you learn how to find simple square roots, imperfect squares, square roots of fractions and decimals, and to estimate square roots.

☐ 3. **Ratio and Proportion** . . . . **Pages 12 - 20**

This section shows how to establish ratios and solve proportion problems.

☐ 4. **Positive and Negative Numbers** . . . . **Pages 21 - 32**

You study addition, subtraction, multiplication, and division of signed numbers in this section. Exponents and roots are also explained.

☐ 5. **Vectors** . . . . **Pages 33 - 53**

The term "vector" is defined. You learn how to solve problems vectorially by means of vector arithmetic. There is a section on vector calculations and a discussion of the Pythagorean Theorem for vector solutions.

☐ 6. **Circuit Calculations** . . . . **Pages 54 - 59**

This important section contains hints and examples on how to solve problems. There are also some problems to give you practice.

☐ 7. **Answers to Self-Test Questions** . . . . **Pages 60 - 67**

☐ 8. **Answer Lesson Questions.**

☐ 9. **Start Studying the Next Lesson.**

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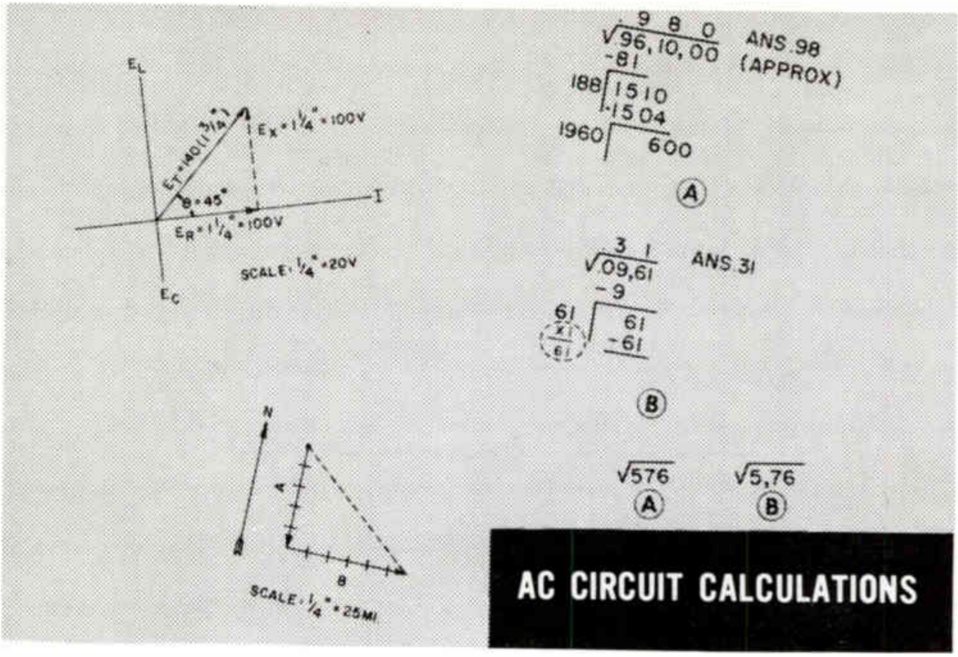


AC CIRCUIT CALCULATIONS

In your reference lesson on dc circuit calculations, you reviewed and studied many of the operations of basic arithmetic. You learned how simple addition, subtraction, multiplication, and division can be used in your work with electronics and electronic circuits. In this reference lesson you will take another step in your study of electronics by learning how to apply these same fundamental operations when solving ac circuit problems. However, as you learned when you studied coils and capacitors, alternating current reacts much differently from direct current in certain circuits. For this reason, you will have to expand your knowledge of basic mathematics in order to handle some of these conditions.

One of the first things you learned in dealing with alternating current is that the reactance of coils and capacitors causes the voltage and current to be out-of-phase with each other, while any resistance tries to keep them in phase. Consequently, you cannot add or subtract these ac circuit quantities without taking these phase differences into consideration. Although this might have seemed pretty difficult at first, you quickly learned that it could be done quite easily by using vectors to represent the phase relationships as well as the values. Then, by adding and subtracting the vectors, you were able to account for both the phase and the size of the circuit quantities.

While there is really no limit to the circuit solutions you can obtain by using simple vector measurement methods, they are very awkward and clumsy for the more complex circuits. For this reason, a number of simpler methods have been worked out to use in practical circuit solutions. Some of them involve square roots, others trigonometry, and one very common system uses a principle known as the j-operator. Like many other new subjects or methods, you will have to learn a few basic rules in order to use them with confidence and accuracy.

In addition to knowing how to do square roots, you should be very familiar with positive and negative numbers. In this lesson we will discuss finding the square roots of numbers, which is really a special type of division. You will also study positive and negative numbers, ratio and proportion, and take a closer look at vectors. Remember, you are not going to try to learn all there is to know about these subjects. You are simply going to look at them from the standpoint of their practical application in electronics.

Even though this is a reference lesson, it is still required for your course. Submit the answers to the questions at the back of the book just as you do for the technical lessons.

Square Roots

In our discussion of coils and capacitors we mentioned that if you knew how to do square roots, you could use a mathematical solution for finding the impedance in ac circuits. We even discussed the formula for this method, which is

$$Z = \sqrt{R^2 + X^2}$$

where Z is the impedance, R is the resistance, and X is the total reactance. The reactance may, of course, be either the inductive reactance, X_L, capacitive reactance, X_C, or a combination of both X_L and X_C.

This is a very handy formula for finding impedance and you will probably use it many times in your work with ac circuits. However, like many good methods of working problems, it is of no use unless you know how to do square roots. So let's take a look at this process, which is known as finding the square root of a number. Even if you have already studied square roots it will still be a good idea to read this section to refresh your memory.

When you studied multiplication you learned that the product of a number multiplied by itself was called a "square." You also learned a special way of indicating the process of finding a square by placing a small "2" above and to the right of the number. Thus, 6 X 6 can be indicated as 6^2, or 136 X 136 as 136^2. Any other number times itself can be indicated the same way.

Many times in your work with electronics you will have the "square" of a number and will want to know the number. There is a special process of division that can be used to find the "squared" number. Since the number that makes a square when it is multiplied by itself is sometimes called the "root" of a square, this special division process is called finding the "square root."

Let's make sure you understand this. A number multiplied by itself, or "squared," makes a product called a "square." The number that is squared is called the "root" of the square. The special division to find the root of a square is called finding the "square root."

SIMPLE SQUARE ROOTS

Now that you have seen what we mean by square root, let's look at a typical example and learn how to solve it. Suppose you are asked to find the square root of the number 576. What you want to know is: "What number multiplied by itself will give me a product of 576?" The main difference between this and any other division problem is that here you are given only the product to work with. Instead of being given a product and one number and being asked what number when multiplied by the given number will equal the product, you are simply given a product and are asked to find the one number that can be multiplied by itself to give this product.

This process is not as difficult as it may sound. It is just a matter of learning a few rules and how to apply them. First, you must set up the number as you would any other division problem, as shown in Fig. 1A. However, you will notice that there is one major difference besides the fact that

$\sqrt{576}$ $\sqrt{5,76}$

Ⓐ Ⓑ

Fig. 1. Setting up a square root problem.

there is no divisor. It's the symbol that looks like a lopsided letter V that is in front of the dividend ($\surd$). It replaces the straight vertical line in a standard division symbol and is called a "radical" sign. This radical sign is the symbol for finding the root of a number and is always used in a square root problem.

In a square root, just as in any other division, you do not tackle the whole number at once. You split it up into smaller numbers and work with them a few at a time. However, in square roots you do it a little bit differently. You will notice that in Fig. 1B we have placed a comma between the 5 and the 7. This breaks our number up into two numbers, 5 and 76. The method for breaking these numbers up in this way is quite simple. You merely start at the extreme right of the whole number and work toward the left, placing a comma after each group of two numbers. Thus, starting with the 6 and working toward the left we have our first group, 76, and then the 5. Since the 5 is the last number on the left in this particular problem, you have only two groups, one of which is a single number.

Grouping the numbers in this way under the radical sign completes the setup. You are now ready to go to work. You will remember that in division you used a basic multiplication table containing all the products for various combinations of the numbers from 1 to 9. After you had a division problem set up, you tried various products to see which one would go into the dividend. In a square root, you do much the same thing except that you need to know the squares of the numbers from 1 to 9. Fig. 2 is a basic multiplication table showing all the squares of the numbers from 1 to 9 marked with stars. This table and these squares are all you need to work any square root problem.

Now, let's look at the problem again, as shown in Fig. 3A, where it is set up and ready to work on. Since we have broken the number up into two groups, and since the number 5 is alone in the first group, we consider the 5 first. We don't have a divisor to divide into the 5, so we must make one. We do this by determining the largest square that will go into 5. Looking at the table, we see that 2 squared is equal to 4, which is smaller than 5, and 3 squared is equal to 9, which is larger than 5. Since the square of 3 is larger than 5, the square of 2 is the largest perfect square that will go into 5.

Therefore, 4 becomes the first trial product and the 2, which is the square root of 4, is the first trial divisor. Now

*1	2	3	4	5	6	7	8	9
2	*4	6	8	10	12	14	16	18
3	6	*9	12	15	18	21	24	27
4	8	12	*16	20	24	28	32	36
5	10	15	20	*25	30	35	40	45
6	12	18	24	30	*36	42	48	54
7	14	21	28	35	42	*49	56	63
8	16	24	32	40	48	56	*64	72
9	18	27	36	45	54	63	72	*81

Fig. 2. The basic multiplication table showing squares of numbers from 1 to 9.

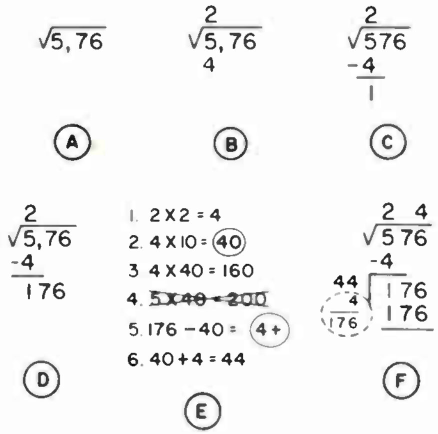


Fig. 3. Steps for working out a square root problem.

that we have found that 4 is the largest square that will go into 5, we place it under the 5 as shown in Fig. 3B. Then, we take the 2, which we squared to get the 4, and place it above the line over the 5 to indicate that it is the first digit of the quotient. This is also shown in Fig. 3B. Next, we subtract the 4 from the 5 to get the first remainder, which is 1, as shown in Fig. 3C. By finding the largest square that will go into the first group in our dividend, we have obtained the first trial product, the first remainder, and the first digit in the quotient.

This first step is the only time we have to use the square of a number when doing square roots. As you can see we never have more than two numbers in any group. The largest number we can possibly have in the first group is 99, and 9 squared, or 81, is the largest square that can go into 99 because 10 squared is 100. This is the reason why we never need more than the basic squares of the numbers from 1 to 9 in order to find the square root of any number.

From now on the problem becomes more like regular division except for the way of obtaining the trial divisors and trial products.

Looking at Fig. 3D, you see that the next step is to bring down the next group of numbers, which is 76. Notice that we bring down the whole group, not just the 7. When we have placed the 76 beside the 1 as shown, we have a trial dividend of 176. Now we must learn the rule by which we establish the next trial divisor. To do this, we take the partial quotient of 2, double it, and then multiply the result by 10.

Following this rule, the partial quotient is 2. If we double it, we get 4. Multiplying the 4 by 10 gives us 40. We use the 40 as the trial divisor. Now we ask ourselves: "How many times will 40 go into 176?" We know that 4 times 40 is 160 which will go into 176 easily. Since 5 times 40 is 200, which is too large to go into 176, 4 is the number we want.

However, we are still not quite finished with the trial divisor. Before we can use it, we have one more step to do. After we have determined that 4 is the largest number of times that 40 will go into 176, we must then *add* the 4 to 40 as shown in Step 6 of Fig. 3E. This gives us 44 which we use as the final trial divisor, as shown in Fig. 3F.

Now, we must multiply 44 by 4 to see if it will still go into 176. As you can see, 4 times 44 is exactly 176 and we will have no remainder when we subtract. Since the trial divisor did go into 176 four times, the second number of the quotient is 4 and can be placed above the line over the second group of numbers. There is no remainder; therefore, the complete quotient is 24, which is the square root of 576. We can prove this by squaring 24, which will give the product of 576.

Although the process of finding the

square root of a number is not difficult, it requires a firm knowledge of some important rules. For this reason we will work out another problem dealing with a larger square. Then you will have a good review of the process as well as some practical experience. Remember, no matter how large the number may be you proceed in the exact same way.

Working Square Root Problems. Let's find the square root of 186,624.

First, set up the problem under the radical sign. Next, separate the number into groups of two numbers, starting at the right and working toward the left, as shown in Fig. 4A. In this problem the radicand (the special name given to the dividend in a square root) is divided evenly into three groups of two numbers each. Since the first group is the number 18, we will find the largest square that will go into 18.

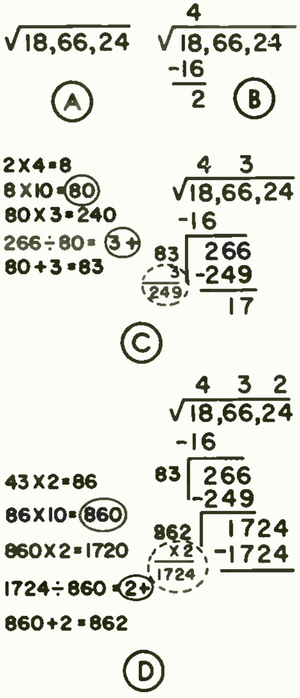


Fig. 4. Finding the square root of a six digit number.

Looking at the multiplication table in Fig. 2 we see that the square of 4 is 16 and that the square of 5 is 25. Twenty-five is larger than 18, so 16 must be the largest square smaller than 18. Therefore, we place the 16 under the 18 in our radicand and subtract, as shown in Fig. 4B. Since 4 is the number that we squared to obtain this trial product, it is the first trial divisor and we place it in the quotient over the number 8 in the first group.

Next, subtract 16 from 18 to get a remainder of 2. Then bring down the next group of two numbers, 66, and place them beside the 2. This gives us a new number, 266, to use as the dividend for the next step, as shown in Fig. 4C. Now you must determine the second trial divisor. Remember, double the existing quotient (4) and then multiply by 10, giving us 80 as shown. Then see how many times 80 will go into 266. For this particular problem, 80 will go into 266 three times. Therefore, we *add* 3 to 80, giving 83 as the second trial divisor. Now, multiply 83 by 3 to get the trial product of 249 which can be subtracted from 266. This subtraction gives a remainder of 17, which is shown in Fig. 4C. Since the trial divisor of 83 went into 266 three times, enter the 3 in the quotient above the line over the second group of numbers, 66.

In this problem we still have another group of two numbers left in our radicand, so we are not finished yet. Therefore, we must bring the 24 down beside the 17 to get the dividend for the next step. As you can see in Fig. 4D, this gives 1724 and you must find a trial divisor for it so that you can find the next number for the quotient.

Proceeding as before, you take the partial quotient, 43, double it to get 86, and then multiply the product by 10, giving you 860. You can see that 860 will go into 1724 only two times. Therefore, you *add* 2 to 860, making 862 the trial divisor. Now, multiplying 862 by 2 gives exactly 1724 and you can subtract without having any remainder. Finally, you place the 2 in the quotient above the 24, giving you the complete square root of 186,624, which is 432. You can check this, of course, by multiplying 432 by itself to see if the product is equal to the radicand you started with.

Although the rules for doing square roots are a little different from those involved in other types of division, they are not any more difficult. Like anything else, it takes practice to become proficient at finding square roots. Most of us don't get this practice after we leave school, so we are likely to forget how to do it. However, in electrical work, square roots can be quite important. Let's try another problem.

In Fig. 5 we have set up the number 7,306,209 to find its square root. Notice that the complete radicand contains seven numbers so it can't be divided evenly into groups of two. Since we always start at the right end of the radicand, we form the groups as shown In this way, a single number will be the first number to the right of the radical sign.

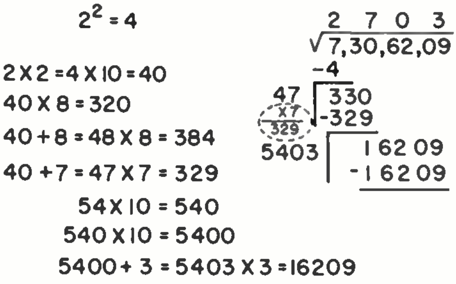


Fig. 5. Another square root problem.

Now, we examine the number in the first group to find the largest square that will go into it. In this problem, the first group is only one number, 7. The largest square that will go into it is 2^2, or 4. Thus, we place a 2 in the quotient or root, directly over the 7. Then we place the square of 2, which is 4, under the 7 and subtract, giving a remainder of 3.

Bring the next group, 30, down beside the 3. Double the root number, 2, making it 4 and multiply it by 10 for the next trial divisor. Now, we determine how many times 40 will go into 330. It looks as if 8 will work because 4 X 8 = 32. However, when we add 8 to 40 to get a trial divisor of 48, we find that 48 X 8 = 384, which is larger than 330. Therefore, we will have to try the next smallest number which is 7.

Notice that we don't multiply 48 X 7. We change the whole trial divisor of 48 to 47 and then multiply 47 X 7 which is equal to 329. In a square root, we often have to reject trial divisors and use new ones that are smaller. Since 329 is smaller than 330, we place the 7 in the root and subtract 329 from 330. This gives a remainder of 1 and we bring down the next group, 62, from the radicand, giving us our new remainder, 162.

We double the two numbers in the root, 27, to get a new trial divisor, which is 54 times 10 or 540. It is obvious at a glance that 540 will not go into 162. Therefore, we place a zero in the root above 62 and then bring down the next two numbers, which are 09. The remainder now becomes 16209.

We double the three numbers in the root, 270, to get the next trial divisor, which is 540 times 10 or 5400. This number (5400) looks as if it will go into

16209 about 3 times. So we add 3 to 5400 to get 5403 and then multiply this number by 3 and get exactly 16209. Since we have no remainder, the problem is completed and we place the 3 in the quotient, or root, above the last group of numbers. Thus, we have found that the square root of 7,306,209 is 2703, which we can prove to be correct by squaring 2703 to get the original radicand.

IMPERFECT SQUARES

So far all the answers have been the roots of perfect squares. Although this is convenient, it does not often happen in practice. There will usually be a remainder, which must be accounted for by making the root end with a decimal number or a fraction. For example, suppose the radicand for the last problem that you worked had been 7,306,976 instead of 7,306,209. If this had been the case, the problem would have worked the same way until you had reached the last part of it, as shown in Fig. 6.

As you can see, the trial product of 5403 X 3 is equal to 16209, but because the original radicand was changed you have a remainder of 767 when you subtract. This is not large enough to increase the root by another whole number to make it 2704, but it does leave a fraction. If the need for accuracy is such that you want to carry the root of 2703 into its fractional part, you would continue the problem as shown in Fig. 6.

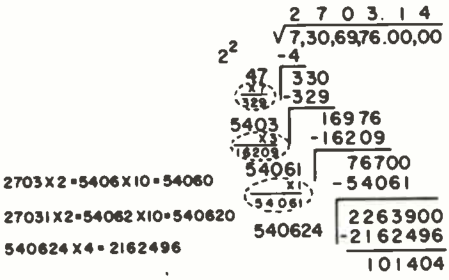


Fig. 6. An imperfect square root carried two places.

To do this, you place a decimal after the last number in the radicand and then add a group of two zeros for each decimal place you want in the root. Notice that there are two zeros added for each decimal place in a square root instead of only one zero, as there is in regular division. In this particular problem, we have carried the answer to two decimal places and have added four zeros as shown.

After you have added the zeros in the radicand and the decimal point in both the radicand and in the root number, you continue in the same manner as before to find the new root numbers. Bring down the first group of two zeros beside the remainder of 767 to give 76700 for the next dividend. Then you double the existing root number, 2703, and multiply the product by 10 to get the trial divisor, 54060. You can quickly see that this will go into 76700 only once, so you add the 1 to it as shown. Then, since any number multiplied by 1 is that same number, you have 54061 for the trial product. Place the 1 in the root.

Subtracting 54061, you get a remainder of 22639. Bring down the next two zeros as shown. Now, double the quotient and multiply by 10, ignoring the decimal in the quotient. In other words, multiply 27031 by 2 to get 54062 and then multiply by 10, making it 540620. Continue as before to find the next root number, which is 4. As you can see, this gives a root of 2703.14 to two decimal places. Since we still have a remainder we do not have a perfect root. Except where extreme accuracy is needed, two decimal places in the answer are enough. Of course, if you do want more accuracy, you would simply continue in the same way by adding two more zeros for each additional decimal place.

You can check your answer in the usual way by squaring the root to see if you get your original radicand. In this problem, if you square 2703.14, you will get an answer of 7,306,965.8596. It is not exactly the same as the original radicand because we did not have a perfect square to start with. However, you can see that the root is close enough and is correct to two decimal places, which is all we are interested in.

FRACTIONS AND DECIMALS

Many times in electronics you will need to find the square root of a fraction or decimal. While the process for finding the roots of fractions or decimals is nearly the same as it is for whole numbers, there is one important thing to remember. The square root of a fraction or decimal will always be larger than its square. You will recall that the product of any two fractions or decimals is always smaller than either of the two numbers. Therefore, the square of any fraction or decimal must also be smaller than the numbers squared.

Finding the square root of fractions is usually very easy, because most fractions have small numbers in both the numerator and the denominator. Also, finding the square roots of small numbers does not involve much work. The first thing to do to find the square root of a fraction is to reduce the fraction as much as possible. Thus, if you wanted to find the root of 6/32, you would first reduce it to 3/16, as shown in Fig. 7A.

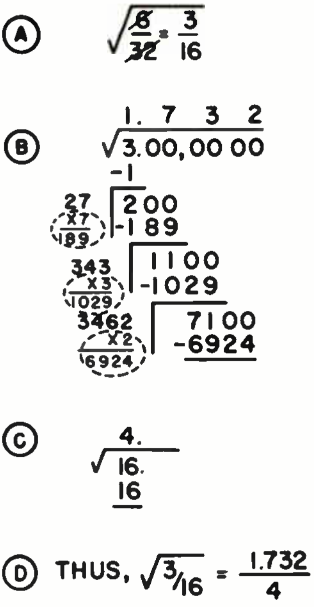


Fig. 7. Finding the square root of a fraction.

Next, separate the numerator and the denominator and find the square root of each one separately, using the same method that you learned for whole numbers. Thus, you would find the square root of 3, which is 1.732 to three places, as shown in Fig. 7B. Then find the square root of 16, which is 4. Now use the root of 3 as the new numerator and the root of 16 as the new denominator. Thus, the square root of 3/16 is 1.732/4 as shown in Fig. 7C. By using this simple method, you can find the square root of any fraction quickly and accurately.

In finding the square root of a decimal, you proceed exactly the same as for a whole number except the grouping will be different when you set up the problem. You still separate the decimal number in groups of two numbers, but with a decimal you start at the decimal point and work to the right. You must always have an even number of digits to the right

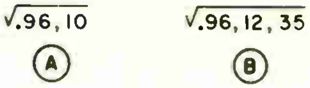


Fig. 8. Setting up a decimal for a square root.

of the decimal place. That is, each group must have two digits. Thus, to set up the decimal .961 for finding its square root, you proceed as shown in Fig. 8A.

After you have placed the number under the radical sign, start at the decimal point and count two numbers to the right and place a comma between the 6 and the 1. Then add a zero after the 1, so that the second group has two digits. If the number were .961235, you would place commas after the 6 and after the 2, as shown in Fig. 8B. The fact that you work from the decimal point to the right in the grouping of the digits is the only difference in the method of finding the square root of a decimal from that of a whole number. In Fig. 9 we have worked out the square root of two decimals. You should not have any trouble in following these examples.

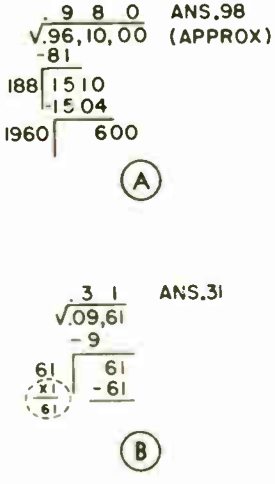


Fig. 9. Finding decimal square roots.

ESTIMATING SQUARE ROOTS

Now that you have seen how to work out the square roots of numbers in detail, let's see how we can apply this process in ac circuits. Suppose, for example, that we want to find the impedance of the circuit shown in Fig. 10. By using the formula

$$Z = \sqrt{R^2 + X^2}$$

and substituting for the values of R and X, we have:

$$Z = \sqrt{50^2 + 60^2}$$

as shown in Step 2 of Fig. 10.

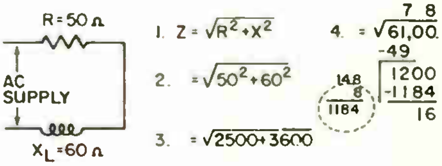


Fig. 10. Using a square root to find impedance.

In working square roots you must follow the rules of order just as in doing any other math. Therefore, the next thing you must do is to perform all the multiplication under the radical sign. This is shown in Step 3. Next add the two squares, which gives 6100. Now go ahead as shown in Step 4. This gives the circuit impedance of 78 ohms and automatically takes care of the phase relationships without having to work with vectors.

Many times, instead of working out the square root of problems accurately, it will be much easier to estimate the answers. For example, take the number 6436. You can see that 80 X 80 is equal to 6400, which gives a remainder of 36. For most purposes this would be close enough, so we would use 80 as the answer.

Likewise, with a number such as 7548, you can see that it is more than 80^2 (6400), but less than 90^2 (8100). Therefore, it would be easy to guess that 84^2 might be close, since 7500 is a little less than halfway between 6400 and 8100. If we square 84, we will find that it is equal to 7056, which is somewhat less than 7548.

When we are this far off in our estimate, the next number we would try would probably be 86 or 87. Let's square 87 and see what we get.

$$\begin{array}{r} 87\\ \underline{87}\\ 609\\ \underline{696}\\ 7569 \end{array}$$

As you can see, this is very close. The difference between 7569 and 7548 is only 21, and unless you require extreme accuracy, you would use 87 as the square root of 7548. By estimating in this way, you can come very close to the square root of any number with a little practice. For large numbers it is generally much easier than working out the root in detail. Try the following problems and see if you can get the answers we have shown:

Find the square root of 625.

Solution:

$$\begin{array}{r|l} & \;\;2\quad 5\\ & \sqrt{6,25}\\ & -4\\ \hline 45 & \;\;2\;25\\ & \underline{-2\;25} \end{array}$$

Find the square root of 11025.

Solution:

$$\begin{array}{r|l} & \;\;1\quad 0\quad 5\\ & \sqrt{1,10,25}\\ & -1\\ \hline 205 & \;\;10\;25\\ & \underline{-10\;25} \end{array}$$

What number when multiplied by itself gives 8,094,025?

Solution:

$$\begin{array}{r|l} & \;\;2\quad 8\quad 4\quad 5\\ & \sqrt{8,09,40,25}\\ & -4\\ \hline 48 & \;\;4\;09\\ & -3\;84\\ \hline 564 & \;\;25\;40\\ & -22\;56\\ \hline 5685 & \;\;2\;84\;25\\ & \underline{-2\;84\;25} \end{array}$$

SELF-TEST QUESTIONS

(1) What is the name given to the symbol which is used to indicate a square root ($\sqrt{\quad}$)?

(2) What is the impedance of an ac circuit containing, in series, a resistance of 15 ohms and a total reactance of 20 ohms?

(3) Find the square root of 2 to three decimal places.

(4) Find the square root of 25/625.

(5) What number when multiplied by itself gives 12,321?

(6) Find $\sqrt{449.44}$.

(7) An inductor with an inductive reactance of 30 ohms is connected in series with a 40 ohm resistor. What is the total impedance?

(8) Find $\sqrt{439569}$.

(9) Find $\sqrt{.000441}$.

(10) Find $\sqrt{25.1001}$.

Ratio and Proportion

There are many times in electronics work when we want to compare quantities. Sometimes we can simply say that something is either larger or smaller than something else, but usually this does not give us enough information. In electronics, as in any other scientific work, we need exact information as to sizes or quantities. For example, saying that one resistor is larger than another is not enough. We must know how much larger it is if we are going to use the resistors for anything practical.

Although we can subtract one quantity from another to find out how much larger it is, there are many times when this type of specific information is not too useful. For example, suppose we want to compare the efficiencies of two electrical circuits. Let's say that one circuit has an input of 400 watts and an output of 300 watts, while the other has an input of 568 watts and an output of 426 watts. If we subtract the input from the output in the first circuit, we find that it has a loss of 100 watts (400 watts – 300 watts). The second circuit, on the other hand, has a loss of 142 watts (568 watts – 426 watts).

By subtracting we find that the loss in the second circuit is 142 watts as compared to a loss of only 100 watts in the first circuit. However, we still don't know which circuit is the more efficient. We know that 42 watts more power is consumed in the second circuit, but since the input and output of this circuit are also larger, this does not tell us anything about its efficiency.

However, there is a method by which we can quickly and accurately compare the losses in the two circuits and determine their relative efficiencies. This is actually a form of division and is known as establishing ratios. For example, if we divide the output of the first circuit by its input and reduce the resulting fraction, we have;

$$\frac{300}{400} = \frac{3}{4}$$

This fractional value of 3/4 tells us that three-quarters of the input power appears as useful output. The remaining one-quarter is the loss in the circuit.

If we do the same thing to the second circuit, we have,

$$\frac{426}{568} = \frac{3}{4}$$

because 142 will go into the numerator 3 times and into the denominator 4 times. Thus, the ratio of the output to the input of the second circuit is exactly the same as the ratio of the output to the input of the first circuit. Their ratios are both 3/4 and, therefore, their efficiencies are the same. In other words, for every 4 watts of input we will get 3 watts of output.

By establishing ratios in this way, we can make many accurate comparisons between various quantities. In addition, through a process known as proportion, we can use an established ratio to compute circuit values much more simply and quickly than we could in any other way. In this section of the lesson, you will learn the rules for establishing ratios and how to apply the ratios in circuit computations.

ESTABLISHING RATIOS

When two quantities are compared by division, we call the ratio of the two quantities the "quotient." Thus, when we divided 426 by 568 and then reduced the resultant fraction to its lowest possible form, we had the ratio of 3/4. We can write such a ratio as the fraction 3/4, or we can use two dots as a ratio sign and write it 3:4. In either case, we say that the ratio is "3 to 4."

In establishing ratios for use in comparing quantities, we must always be sure to express the two quantities in the same units. For example, we can't compare 10 volts with 10 millivolts. We must either change the 10 volts to 10,000 millivolts or change the 10 millivolts to .010 volts before we can establish a ratio between them. Also, the quantities themselves must be of the same kind. We can't, for example, compare a volt with an ampere, or an ohm with a watt. However, there are many times when we can compare seemingly unlike quantities by changing both of them to a third quantity.

For example, suppose a motor's output is 5 horsepower and its input is 4 kilowatts. If we want to establish an output-to-input efficiency ratio for this motor, we can do it quite simply by converting our values. One horsepower is equivalent to 746 electrical watts. To simplify our calculations we will use 750 watts as an approximation. Thus, we can convert 5 horsepower to 5 X 750 or 3750 watts. We also know that 4 kilowatts is equal to 4000 watts. So, by converting both the output and the input to a common unit such as watts, we are able to establish the following ratio:

Given: Output = 5hp
Input = 4kW
Find: Efficiency

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}}$$

$$= \frac{5\text{hp}}{4\text{kW}} = \frac{5 \times 750}{4 \times 1000}$$

$$= \frac{3750}{4000} = \frac{15}{16} = 15{:}16$$

Thus, the efficiency of the motor can be expressed as the ratio of 15 to 16. If we prefer, we can change the ratio to a percentage value by dividing as follows:

$$\begin{array}{r} .9375 \text{ or } 93.75\% \\ 16\overline{)15.0000} \\ \underline{144} \\ 60 \\ \underline{48} \\ 120 \\ \underline{112} \\ 80 \\ 80 \end{array}$$

In this way, we can express a ratio as a fraction, a decimal value, or a percentage.

The rules for establishing ratios are quite simple. To find the ratio of two similar quantities:

1. Convert the quantities to the same units of measurement.
2. Form a fraction using one quantity as a numerator and the other quantity as a denominator.
3. Reduce the fraction to its lowest possible form.
4. If you wish, you can divide the denominator into the numerator to express the ratio as a decimal or as a percentage.

PROPORTION

Even though ratios are extremely useful for comparing similar quantities, they

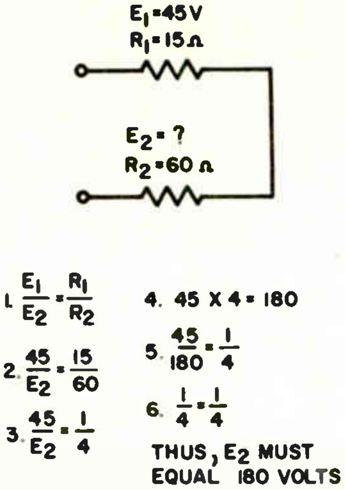


Fig. 11. Using ratio and proportion to solve for circuit values.

are probably even more useful as a computing tool. By setting certain ratios equal to each other in what is known as a proportion, we are able to make many shortcuts in circuit calculations. For example, suppose we had a circuit such as the one shown in Fig. 11 and wanted to know the voltage across R_2. Ordinarily, in a series circuit such as this, we would first find the current through R_1 by using the formula $I = E_1 \div R_1$. Then, since the current is the same in all parts of a series circuit, we would find E_2 by multiplying I by R_2. However, by using ratio and proportion we can find either the voltage across R_2 or the total voltage in one simple operation, without ever knowing the current at all. Thus, ratio and proportion save time and work by eliminating the step of finding the current.

In order to use proportion, you have to remember one simple rule. That is, a proportion is a mathematical statement that two ratios are equal. For example, refer back to the efficiency problem in the two circuits you studied earlier in this lesson. You recall that in the first circuit we had an efficiency of

$$\frac{300}{400} = \frac{3}{4}$$

Likewise, in the second circuit the efficiency was

$$\frac{426}{568} = \frac{3}{4}$$

Thus, both of the ratios are equal and we can actually indicate this mathematically as

$$\frac{300}{400} = \frac{426}{568}$$

because, when we reduce both fractions, we have 3/4 on both sides of the equal sign. Therefore, it is a proportion because it contains two equal ratios.

Now, let's see how we can apply this type of thinking to the circuit in Fig. 11. First, let's establish a resistance ratio for the circuit. We do this by dividing R_1 by R_2 to get the ratio 15/60 or 1/4. Now, let's find the current in the circuit by dividing E_1 by R_1 and then find the voltage across E_2 by using the method we are familiar with. If we do this, we find that:

$$\begin{aligned} I &= E_1 \div R_1 \\ &= 45 \div 15 = 3 \text{ amps} \\ \text{Then, } E_2 &= R_2 \times I \\ &= 60 \times 3 \\ &= 180 \text{ volts} \end{aligned}$$

If we form another ratio from the voltages across E_1 and E_2, we will have

45/180 = 1/4. Notice that this voltage ratio is exactly the same as the resistance ratio and, therefore, the two ratios must be equal. Accordingly, we can establish a proportion with the two equal ratios by stating them mathematically as:

$$\frac{R_1}{R_2} = \frac{E_1}{E_2}$$

or

$$\frac{15}{60} = \frac{45}{180}$$

or

$$\frac{1}{4} = \frac{1}{4}$$

All three expressions are proportions and say exactly the same thing.

Suppose we knew that the resistance and voltage ratios were equal to begin with. Actually, we can easily see that they would be, because the voltage drops around a circuit must distribute themselves in accordance with the size of the resistances. If we had realized this, we could have set up our proportion as shown in Fig. 11 to begin with, and substituted all our known values as follows:

$$\frac{E_1}{E_2} = \frac{R_1}{R_2}$$

Substituting, we have:

$$\frac{45}{E_2} = \frac{15}{60}$$

This, of course, gives us what we call an "equation" that has one unknown value.

Now that we know that the two ratios are equal, we can find the value of E_2 quite simply. If we reduce the 15/60 to its lowest form of 1/4, we have

$$\frac{45}{E_2} = \frac{1}{4}$$

Since one side of our proportion will reduce to 1/4, the other side must also reduce to 1/4 so that the two sides can be equal. Thus, all we have to do is replace the denominator, E_2, in our first ratio, with a number that is equal to 4 times 45. Since 4 X 45 = 180, E_2 must be equal to 180 because 45/180 is the only fraction with 45 as the numerator that will reduce to 1/4. We must be able to reduce both sides to 1/4 in order to have a proportion.

Although this may seem a little complex at first, let's consider the following conditions which should clear it up. If 3 resistors cost 75 cents, we know that 6 resistors must cost $1.50. At the given rate, the cost of the resistors must depend only on the number bought. The more resistors we buy, the larger the cost will be. The fewer we buy, the less the cost will be. When two quantities depend on each other in this way, they are said to be in proportion.

We have already said that a proportion is a mathematical statement that says two ratios are equal. In this problem, the two quantities that make up the ratios are the number of resistors, N, and the cost, C. Since the cost depends on the number of resistors bought, we can write a proportion.

First Purchase	Second Purchase
N_1 = 3 resistors	N_2 = 6 resistors
C_1 = $.75	C_2 = $1.50

The ratio of the number of resistors is:

$$\frac{N_1}{N_2} = \frac{3}{6} = \frac{1}{2}$$

The ratio of the cost is:

$$\frac{C_1}{C_2} = \frac{75}{150} = \frac{1}{2}$$

Since the two ratios are equal, the proportion is written mathematically as:

$$\frac{N_1}{N_2} = \frac{C_1}{C_2}$$

or

$$\frac{3}{6} = \frac{75}{150}$$

or

$$\frac{1}{2} = \frac{1}{2}$$

This is an example of a direct proportion. When two quantities depend on each other so that one increases as the other increases, or one decreases as the other decreases, they are said to be directly proportional. This is what we mean when we say that the current through a fixed resistance is directly proportional to the voltage applied. As the voltage increases, the current increases, etc.

Notice that when we set up two equal ratios as a direct proportion, we must compare the two ratios in the same order. In other words, we used the quantities in the first situation, N_1 and C_1, as numerators, and the quantities in the second situation, N_2 and C_2, as denominators. Thus, they are in the same order because the second ratio, C_1/C_2, is patterned after the first, N_1/N_2. However, we could have written the proportion in the opposite form. For example,

$$\frac{C_1}{C_2} = \frac{N_1}{N_2}$$

or

$$\frac{C_2}{C_1} = \frac{N_2}{N_1}$$

or

$$\frac{N_2}{N_1} = \frac{C_2}{C_1}$$

As you can see, it is not important which ratio is written first or how it is written. However, in a direct proportion, the second ratio must always be written in the same order as the first.

Thus, the rules for setting up a direct proportion for two variables that depend on each other are:

1. Make a ratio of either one of the variables.
2. Make a ratio of the other variable in the same order.
3. Make the two ratios equal to each other.

SOLVING PROPORTIONS

In the first example of a proportion that we solved, we reduced the completed ratio to its smallest possible form. Then we found a number for the unknown in the incomplete ratio that would allow it to be reduced to the same form. While this is actually what we must do in order to find the solution for any proportion, there is a shortcut which we can use that makes it much easier. This shortcut is called "cross-multiplication" and we will learn later how it can be used. It always works and we should learn how to use it.

For example, suppose we have a length of cable that is 78 ft. long and another length of the same kind that is 4 ft. long. We want to know how much the longer piece of cable weighs, but because it is bulky and hard to handle it will be difficult to weigh it. In this case, we could weigh the smaller length of cable and then set up a proportion and find the weight of the longer piece.

Let's say that the shorter piece weighs ten pounds. We would set up the proportion as follows:

$$\frac{L_L}{L_S} = \frac{W_L}{W_S}$$

L_L = length of longer cable
L_S = length of shorter cable
W_L = weight of longer cable
W_S = weight of shorter cable

Now, by substituting values, we have:

$$\frac{L_L}{L_S} = \frac{W_L}{W_S}$$

$$\frac{78}{4} = \frac{W_L}{10}$$

To apply our shortcut using cross-multiplication, we multiply the numerator of one fraction by the denominator of the other as follows:

$$4 \times W_L = 78 \times 10$$
$$4W_L = 780$$

Now we have a familiar equation form to work with and we know that if

$$4W_L = 780\text{, then}$$
$$W_L = 780 \div 4 = 195$$

Therefore, the weight of the large, bulky piece of cable is 195 lbs.

Another example of the same problem in a slightly different situation might be quite common in your work in electronics. Suppose the longer piece of cable were wound on a reel and you wanted to know how long it was without unwinding it. Since it was wound on a reel, it would be easy to handle and we could weigh it quite easily. Then, by weighing the shorter piece, and setting up the proportion using the two weights and the length of the short piece, we could find the length of the long piece. Suppose the cable on the drum weighed 425 pounds, while the short piece was 4 ft. long and weighed ten pounds. First, we would have to subtract the weight of the reel itself, say 25 pounds, and then set up the proportion:

$$\frac{L_L}{L_S} = \frac{W_L}{W_S}$$

$$\frac{L_L}{4} = \frac{(425 - 25)}{10}$$

$$\frac{L_L}{4} = \frac{400}{10}$$

By cross-multiplying, we have:

$$10 \times L_L = 4 \times 400$$
$$10\ L_L = 1600$$
$$L_L = 1600 \div 10$$
$$L_L = 160\text{ ft.}$$

The steps for solving any direct proportion are always the same.

1. Set up the direct proportion:

$$\frac{X_1}{X_2} = \frac{Y_1}{Y_2}$$

2. Substitute numbers where possible:

$$\frac{10}{100} = \frac{50}{X}$$

3. Cross-multiply:

$$10 \times X = 50 \times 100.$$

4. Simplify: $10X = 5000$.

5. Solve for the unknown by dividing:

$$X = 5000 \div 10$$

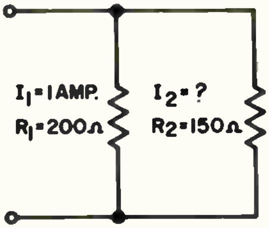
6. Answer: $X = 500$.

Inverse Proportion. So far in our discussion of proportion, we have considered only what happens when two quantities vary directly. Many times two quantities depend on each other, but instead of varying directly they do just the opposite. When one increases, the other must decrease an appropriate amount. When this occurs, we say the two quantities vary indirectly or "inversely" and that they are inversely proportional. The current and resistance in an electrical circuit, with a fixed voltage, is a good example of an inverse proportion. As the resistance increases, the current decreases.

We can set up inverse proportions mathematically just as we do direct proportions except for one major difference. In an inverse proportion, we always set up the second ratio in the opposite or inverse order. For example, consider the parallel circuit shown in Fig. 12.

In this circuit we are given the values of the two resistances and the current through one of them. We could find the current, I_2, by finding the voltage across R_1, and since the voltage across R_2 would be the same we could find I_2 by using this voltage. However, we can solve this problem in a much simpler manner. There is just one thing to remember. The current and the resistance vary inversely and, therefore, we must use an inverse proportion. To do this, we set up the first ratio. It doesn't make any difference which one we use first or how we set it up, as long as we set up the next one in the opposite manner.

For example, in the circuit of Fig. 12, let's use the current ratio first as I_1/I_2. Then, the resistance ratio in the reverse order R_2/R_1, and then set them equal to each other as follows.



1. $\frac{I_1}{I_2} = \frac{R_2}{R_1}$

2. $\frac{1}{I_2} = \frac{150}{200}$

3. $150 \times I_2 = 200 \times 1$

4. $150\, I_2 = 200$

5. $I_2 = 200 \div 150$

6. $I_2 = 1.33$ AMPS

Fig. 12. Using an inverse proportion to solve for current.

$$\frac{I_1}{I_2} = \frac{R_2}{R_1}$$

Substituting, we get:

$$\frac{1}{I_2} = \frac{150}{200}$$

$$\begin{aligned} 150 \times I_2 &= 200 \times 1 \\ 150\, I_2 &= 200 \\ I_2 &= 200 \div 150 \\ I_2 &= 1.33 \text{ amps.} \end{aligned}$$

As you can see, the solution is obtained in exactly the same manner as in a direct proportion. The only difference is that we reversed the order of the second ratio from that of the first when we set up the ratios.

You will recall that when we first discussed establishing ratios we mentioned that a ratio could be written as 5:2 as well as 5/2. We can also write proportions in two ways, depending upon which way we indicate our ratios. For example, the proportion

$$\frac{10}{20} = \frac{50}{100}$$

would be written as 10:20 :: 50:100, using the two dots as ratio signs and the four dots to indicate proportion. When a ratio is written in this way, there is no cross-multiplication indicated, as there is in the fractional form, and we use a different way of indicating the solution.

In the form 10:20 :: 50:100, we give a name to both parts of the proportion. We call the two outside numbers, 10 and 100, the "extremes" of the proportion. The two inside numbers, 20 and 50, are called the "means" of the proportion. Now, we say that the product of the means is equal to the product of the extremes. In other words, the product of the two outside numbers is equal to the product of the two inside numbers. As you can see, remembering this and using it with this form of the proportion gives us exactly the same thing as cross-multiplying a proportion that is written in the fractional form.

$$\frac{10}{20} = \frac{50}{100}$$

$$20 \times 50 = 10 \times 100$$

or

10:20 :: 50:100

$$20 \times 50 = 10 \times 100$$

Using ratios in proportion to solve for unknown quantities is one of the handiest tools in mathematics. It is not only easy to use and work with, but it is easy to remember the rules. No matter where you go or what you do, you can almost always find some use for ratio and proportion in solving problems. You will be very pleased with the amount of work it can save you.

SELF-TEST QUESTIONS

(11) Explain the difference between a ratio and a proportion.
(12) A 2-horsepower motor requires 1.75 kilowatts of input power. What is the efficiency of the motor?
(13) Find the ratio of 6V to 18V.
(14) What is the ratio of 250 millivolts to 1 volt?
(15) Find the efficiency of a 3-horsepower motor which requires 2.5 kilowatts of input power.

(16) A is directly proportional to B. $A_1 = 15$, $A_2 = 6$, $B_1 = 90$; find B_2.

(17) A is inversely proportional to B. $A_2 = 4$, $B_1 = 100$, $B_2 = 150$; find A_1.

(18) R_1 and R_2 are connected in series across a battery. R_1 is a 1200-ohm resistor and drops 10 volts. R_2 is a 240-ohm resistor. What is the applied battery voltage?

(19) R_1 and R_2 are connected in parallel. R_1 is a 66-ohm resistor passing a current of 2 amps. R_2 passes a current of 2.2 amps. What is the value of R_2?

Positive and Negative Numbers

Many of the calculations, graphs, and tables that are used to solve problems in both ac and dc circuits require an understanding of positive and negative numbers. These numbers are commonly called "signed" numbers and are used to indicate opposite amounts. These opposite amounts might be some of the following: gain or loss in voltage, increase or decrease in volume, currents that flow in opposite directions, capacitive or inductive reactance, etc.

In our everyday lives we commonly indicate opposite quantities by various pairs of words, such as north and south, up and down, and gain or loss. In electronics, we use opposite quantities so often that it is much easier to indicate them by using plus (+) and minus (–) signs. For example, 5° above zero is written as +5°, and 5° below zero is written as –5°. A current in one direction would be +10 amps, but a current in the opposite direction would be –10 amps.

Numbers preceded by a minus sign are called negative numbers. A positive number is indicated by a plus sign. However, many times a positive number will not have any sign at all. Thus, a number with no sign is always considered a positive number. A number is never considered to be negative unless it has a minus sign. Generally, increases and gains, and directions to the right and upward are considered to be positive (+). Losses and decreases, directions to the left and downward are considered negative (–).

Since your work in electronics involves signed numbers so often, you must be very familiar with them. You will have to be able to add and subtract them from each other as well as be familiar with multiplying and dividing them. In this section of the lesson you will learn how to perform these basic operations with signed numbers.

ADDING SIGNED NUMBERS

Probably the best way to understand positive and negative numbers is to represent them on a graph as shown in Fig. 13.

Fig. 13. Graph showing arrangement of positive and negative numbers.

As you can see, there is a reference point or zero mark at the center of the scale with the positive numbers extending to the right and the negative numbers to the left. A scale of numbers like this is very handy for showing both addition and subtraction of signed numbers. For example, if we want to add +3 and +5, we start at zero and count three numbers to the right which will bring us to +3. Then, we start at +3 and count five more numbers to the right, which brings us to +8, as shown by the arrows in Fig. 14.

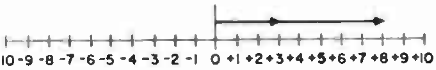


Fig. 14. Adding +3 and +5 graphically.

Thus, adding +3 and +5 gives us +8 which is the same as the addition we studied in basic arithmetic. Likewise, suppose we want to add −4 and −3. We can also do this graphically as shown by the arrows in Fig. 15. Notice that we first count four units to the left of the zero because all negative numbers increase in size as we move toward the left. This brings us to −4. Then we start from −4 and count three more units to the left which brings us to −7. Thus, the sum of −7 is obtained by adding −4 and −3.

Fig. 15. Adding −4 and −3 graphically.

This brings us to the first rule in dealing with signed numbers. When two or more numbers have the same sign (all positive or all negative), they are said to have "like signs."

The first rule for addition of signed numbers is: ***To add two or more numbers with like signs, find the sum of the numbers as you would in ordinary arithmetic and place the sign of the numbers added in front of this sum.*** Thus, the sum of −3, −5, and −7 would be −15; and the sum of +6, +8, +9, and +2 would be +25.

However, we will also be dealing with both positive and negative numbers at the same time. For example, suppose we have to find the sum of +2 and −5. We know how to add two and five when both numbers have the same sign, but here each has a different sign. How will we handle it?

To begin with, let's start with a graph as we did for numbers with like signs. First, we start at the zero reference point and count two units to the right which brings us to +2, as shown by the short arrow in Fig. 16. This takes care of the +2 in our addition and now we can consider the −5. We know that in order to arrive at −5 we would normally start at zero and count five units to the left. However, we are at +2 and must start at +2 instead of zero when we begin to add our −5. Therefore, instead of starting at the zero reference and counting five units to the left, we start at +2 and count five units to the left, as shown by the long arrow in Fig. 16.

This brings us to −3 on the graph. Accordingly, since we have added two arrows, one which is +2 units long and the other −5 units long, and arrived at −3, it follows that the sum of +2 and −5 must be −3. If we look at this addition of two numbers with "unlike" signs closely, we can see that we have actually found the difference between the two numbers (5 − 2 = 3) and then used the sign of the largest number (−5) in front of our answer (−3).

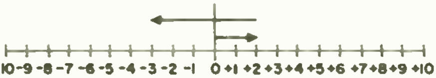


Fig. 16. Adding numbers with unlike signs graphically.

The second rule for addition of signed numbers is: ***The sum of two signed numbers with unlike signs is equal to the difference between the two numbers, preceded by the sign of the largest number.*** Remember that although we find the difference of the two numbers, it is not subtraction. It is the addition of numbers with unlike signs.

Here are a few examples of the addition of signed numbers following the two rules which we have learned. Try them and see if you get the same answers that we do.

$$\begin{array}{rrrrr} -\ 7 & -9 & +10 & -63 & +1/2 \\ \underline{-\ 8} & \underline{+7} & \underline{-\ 6} & \underline{+46} & \underline{-1/4} \\ -15 & -2 & +\ 4 & -17 & +1/4 \end{array}$$

$$\begin{array}{rrrr} -.25 & +\ 5 & +6 & -20 \\ \underline{+.05} & \underline{+\ 6} & \underline{-5} & \underline{+18} \\ -.20 & +11 & +1 & -\ 2 \end{array}$$

SUBTRACTING SIGNED NUMBERS

When you studied basic subtraction in earlier lessons, you asked, "What number must be added to a given number to give another given number?" In other words, in subtracting 5 from 9 you asked, "What number added to 5 will give 9?" The answer is 4, because 4 + 5 is equal to 9. In subtracting signed numbers you do exactly the same, but you have to be very careful to watch the signs.

For example, consider the problem of subtracting –4 from –9. In order to do this, we ask what number added to –4 will give us –9. Of course, there is only one number and that is –5, because –4 + (–5) is equal to –9. Therefore, –4 from –9 is equal to –5.

We can also illustrate this graphically as shown in Fig. 17. First, we draw an arrow from the zero point to –9 as shown by the long arrow. Then, we draw an arrow from zero to –4 to represent the value (–4) that we are subtracting, as shown by the short arrow. Now, if we count the units between –4 and –9 as shown by the dotted arrow, we can see that we have five units to the left which means that –5 is our answer.

Now that we know what happens when we subtract a positive number from a positive number, (+9) – (+5) = +4, and also what happens when a negative number is subtracted from a negative number, (–9) – (–4) = –5, let's consider the subtraction of numbers with unlike signs. Suppose that we want to subtract –3 from +6. First, we ask ourselves, "What number added to –3 will give us +6?" If we look at this closely, we will see that +9 is the only number that can be added to –3 to give us +6 because,

$$(+9) + (-3) = +6$$

Therefore, (+6) – (–3) must be equal to +9.

Fig. 18 shows this graphically. First, we draw an arrow from zero to +6 to represent +6. Then, we draw an arrow from zero to –3 to represent –3. Now, we start at the –3 and count towards the right to see how many units would have to be added to –3 to give us +6. If we count off these units, we will find that there are nine of them. Since we move from left to right, the 9 must be +9. Thus, we can prove that

$$(+6) - (-3) = +9$$

Suppose, however, that we have the same numbers with the signs reversed. What is (–6) – (+3) equal to? Once again,

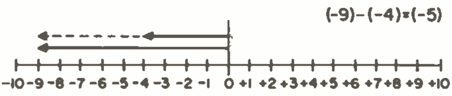


Fig. 17. Subtracting signed numbers graphically.

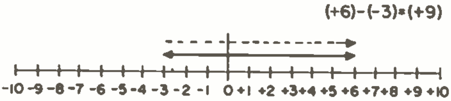


Fig. 18. Subtracting numbers with unlike signs.

we ask ourselves, "What number added to +3 will give −6? Of course +3 plus −9 is the only answer. Therefore, (−6) − (+3) must be equal to −9. Graphically, we can show this in Fig. 19. We draw an arrow from zero to −6. Then we draw an arrow from zero to +3. Now, we can see that −6 is nine units to the left of +3, as shown by the dotted arrow. Since we go to the left, this 9 must be −9.

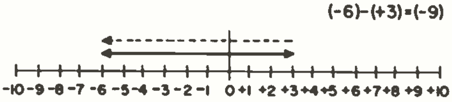


Fig. 19. Subtracting +3 from −6 graphically.

Now look carefully at the examples that we have just discussed:

$$\begin{array}{r} +9 \\ -(+5) \\ \hline +4 \end{array} \quad \begin{array}{r} -9 \\ -(-4) \\ \hline -5 \end{array} \quad \begin{array}{r} +6 \\ -(-3) \\ \hline +9 \end{array} \quad \begin{array}{r} -6 \\ -(+3) \\ \hline -9 \end{array}$$

Notice that they all have one thing in common. That is if we change the sign in the subtrahend (the number subtracted), and then add the two numbers, we will get the proper answer. For example, consider the problem of:

$$\begin{array}{r} -9 \\ -(-4) \\ \hline -5 \end{array}$$

If we set this up and change the −4 to a +4 as

$$\begin{array}{r} -9 \\ +4 \\ \hline \end{array}$$

and then add, we will get −5 for the answer.

The rule for subtracting signed numbers is: ***To subtract signed numbers, change the sign of the number you wish to subtract (subtrahend) and then add the two numbers.*** This rule will work for subtracting any two signed numbers no matter how small or large they may be. We have given some examples for you to try. Notice that the numbers and their signs are enclosed in parentheses so they will not be confused with the subtraction (−) sign.

1. $(-25) - (-15)$
   $= (-25) + (+15) = -10$
2. $(-18) - (+6)$
   $= (-18) + (-6) = -24$
3. $(+29) - (+7)$
   $= (+29) + (-7) = +22$
4. $\left(-\dfrac{1}{8}\right) - \left(+\dfrac{1}{16}\right)$
   $= \left(-\dfrac{2}{16}\right) + \left(-\dfrac{1}{16}\right) = -\dfrac{3}{16}$
5. $(+.36) - (-.05)$
   $= (+.36) + (+.05) = +.41$

MULTIPLYING SIGNED NUMBERS

You learned that multiplication is the addition of a number to itself an indicated number of times. Thus, 5 × 6 tells us to either add 6 to itself five times or to add 5 to itself six times. The multiplication of positive and negative numbers is just the same, except that we must consider what to do about the signs. In order to do this, let's consider all the possible combinations of signs that we might have in multiplying two numbers.

There are only four possible combinations and they are as follows:

(1) $(+2) \times (+3) = ?$
(2) $(-2) \times (+3) = ?$
(3) $(+2) \times (-3) = ?$
(4) $(-2) \times (-3) = ?$

Now, you already know that the first situation is the same as saying that +2 is to be added three times, or:

$$(+2) + (+2) + (+2) = +6$$

Therefore,

$$(+2) \times (+3) = +6.$$

In the same manner, the second situation simply states that −2 is to be added together three times, or:

$$(-2) + (-2) + (-2) = -6$$

Therefore,

$$(-2) \times (+3) = -6.$$

From what we have seen so far, multiplying two positive numbers together gives us the product of the two numbers preceded by a plus sign. Also, in a similar manner, the product of a negative number multiplied by a positive number is the product of the two numbers preceded by a minus sign. Thus, we have taken care of the first two situations.

The third situation says that we must add +2 to itself −3 times. If we stop to consider this for a minute, we can see that if we add a number to itself a minus number of times, it will be the same as subtracting the +2 from zero three separate times. Therefore, $(+2) \times (-3)$ is the same as $-(+2) - (+2) - (+2)$. If we change the signs and add as we do in any problem of subtracting signed numbers, we have:

$$(-2) + (-2) + (-2) = -6.$$

Thus, $(+2) \times (-3)$ must be equal to −6. This is the same answer we got for the second situation which was

$$(-2) \times (+3) = -6.$$

This is right because you learned that the order in which the numbers are arranged does not make any difference in multiplication. Thus, we can now say that the product of any two numbers with unlike signs is always negative.

Now, let's look at the fourth situation. Here we have $(-2) \times (-3)$, which is the same as saying −2 added to itself −3 times. Once again, adding a number to itself a minus number of times must be the same as subtraction. Therefore, we can write it as

$$-(-2) - (-2) - (-2) = ?$$

However, once again we are subtracting signed numbers and we must change the signs and add. Consequently, we would rewrite the problem

$$(+2) + (+2) + (+2) = ?$$

which of course equals +6. From this, we can say that

$$(-2) \times (-3) = +6$$

and, accordingly, the product of any two negative numbers is always positive.

Reviewing all that we have just discussed, we find that there are two simple rules for the multiplication of two signed numbers:

1. The product of any two numbers with like signs is always positive.

2. The product of any two numbers with unlike signs is always negative.

With these two rules you can handle the multiplication of any two signed numbers.

Sometimes you may have more than two signed numbers to multiply together. In such a case, you simply take the numbers two at a time and then multiply the product by the next number. For example:

$$(-2) \times (+3) \times (-4) = ?$$

First take $(-2) \times (+3)$, which equals -6, then the product $(-6) \times (-4) = +24$. Therefore, $(-2) \times (+3) \times (-4) = +24$.

Another example is:

$$(+2) \times (-5) \times (-7) \times (+11) = ?$$

First, $(+2) \times (-5) = (-10)$
Then, $(-10) \times (-7) \times (+11) = ?$
Now, $(-10) \times (-7) = +70$
Then, $(+70) \times (+11) = +770$

DIVIDING SIGNED NUMBERS

Because division is just the reverse of multiplication, you should not have any trouble learning to divide signed numbers. Remember, when you divide one number by another you ask, "What number, when multiplied by the divisor (the number you divide by), will equal the dividend?" In other words, if you wish to divide 30 by 5 you say, "Since 5 X 6 is equal to 30, then 30 ÷ 5 must equal 6."

In dividing signed numbers you do the same thing, except that you must be careful to obtain the proper sign for the quotient. Once again, let's consider all the possible combinations of signs that we might have in dividing one number by another. There can be only four combinations as follows:

(1) $(+30) \div (+6) = ?$
(2) $(-30) \div (+6) = ?$
(3) $(+30) \div (-6) = ?$
(4) $(-30) \div (-6) = ?$

Because division is the opposite of multiplication, we must have the following:

(1) $(+30) \div (+6) = +5$ because $(+5) \times (+6) = +30$
(2) $(-30) \div (+6) = -5$ because $(-5) \times (+6) = -30$
(3) $(+30) \div (-6) = -5$ because $(-5) \times (-6) = +30$
(4) $(-30) \div (-6) = +5$ because $(+5) \times (-6) = -30$

Therefore, our two rules for division of signed numbers are as follows:

1. If both numbers have like signs, the quotient is always positive.

2. If the numbers have unlike signs, the quotient is always negative.

This is all you need to know in order to handle the division of any two signed numbers.

EXPONENTS AND ROOTS

Let's consider the effect of signs on numbers with exponents or roots. You have already learned that the square of a number is the product of a number that is multiplied by itself. You also learned that you can use a small number "2" written above and to the right of the number to indicate that it is to be squared. Thus, 13^2 means 13 X 13, which is 169. We call the small "2" above the 13 an exponent. When we use 2 as an exponent to indicate the operation of squaring a number, we sometimes say that it means raising the number to its second power.

Just as we can raise a number to its second power by multiplying it by itself, we can also raise numbers to other powers. For example, 13^3 means that the number is to be raised to its third power, or 13 X 13 X 13, which equals 169 X 13 or 2197. In this case, the exponent is a 3 and indicates that the number must be raised to its third power. In the case of the third power of a number, we have a special name for the operation just as we do for the second power (square). For the third power, we call it "cubing" a number, or finding the cube of a number.

Of course, we can raise a number to any power that we desire, simply by multiplying it by itself the proper number of times. In each case, the exponent indicates the power to which the number must be raised. Thus, 23^4 means 23 X 23 X 23 X 23, and 17^6 means 17 X 17 X 17 X 17 X 17 X 17. However, beyond the third power (cube) we have no special names because the operation is not common enough. We simply say the "fourth power of the number" or the "sixth power" or whatever power the exponent may indicate.

If a number has a sign in front of it, we proceed just as we would in multiplying any series of signed numbers. For example, $(-3)^2$ would be

$$(-3) \times (-3) = +9$$

and $(-3)^3$ would be

$$\begin{aligned} & (-3) \times (-3) \times (-3) \\ = & (+9) \times (-3) \\ = & -27 \end{aligned}$$

Likewise, $(-2)^4$ would be

$$\begin{aligned} & (-2) \times (-2) \times (-2) \times (-2) \\ = & (+4) \times (-2) \times (-2) \\ = & (-8) \times (-2) \\ = & +16 \end{aligned}$$

It is interesting to notice that a negative number squared always gives a positive product, while a negative number cubed always gives a negative product. This is true because any two negative numbers multiplied always give a positive product and any three negative numbers multiplied always give a negative product. With a negative number, any even-numbered exponent, such as 4, 8, 28, or 32, always gives a positive product and any odd-numbered exponent gives a negative product.

Just as every number can be raised to any power, every number has an infinite number of roots. You learned earlier in this lesson what is meant by the square root of a number and that this operation is indicated by the use of the radical sign $\sqrt{\quad}$. Therefore, if $13^2 = 13 \times 13$ or 169, then $\sqrt{169}$ is equal to 13. You also learned that $-13^2 = (-13) \times (-13)$ which is also 169. Therefore, we have two possible square roots of 169, either +13 or −13. In fact, any positive square has two possible square roots: a positive root or a negative root. If there is any question as to the sign of a square root, we write the root and use both signs. Thus, we would indicate the square root of 169 as ±13. We read this as "plus or minus 13."

The symbol for a square root is the radical sign $\sqrt{\quad}$. The same basic sign is used to indicate the root of any number, except that we use an "index" number in the notch of the sign to indicate that particular root. Thus, $\sqrt[3]{27}$ means the cube root of 27. We find that it is 3, because 3 X 3 X 3 equals 27. Likewise, $\sqrt[4]{16}$ means that we are to find the fourth root of 16 which is 2, because 2 X 2 X 2 X 2 equals 16. Of course the square or second root of any number should be indicated with an index of 2 in the radical sign as $\sqrt[2]{4}$. However, in square roots it is common practice not to write 2 as the index so we just use the radical sign by itself. Thus, a radical sign with no index always indicates a square or second root and any other desired root must be indicated by using the proper index.

Just as the root of any positive square may be either positive or negative, the even-numbered roots of any number raised to a power may also be either positive or negative. In other words, $\sqrt[4]{16}$ may be either ± because either -2^4 or $+2^4$ is equal to +16. Cube roots, however, or any other odd-numbered roots will be positive or negative depending on the sign of the number. Thus, $\sqrt[3]{27}$ must be +3 because $(+3) \times (+3) \times (+3)$ equals 27. Therefore, $(-3) \times (-3) \times (-3)$ can never be equal to +27; it will always equal −27. So $\sqrt[3]{-27}$ equals −3. The cube root of any negative number must be equal to a negative number. Other odd-numbered roots follow the same rule. For example, $\sqrt[5]{32}$ always equals +2 because;

$$(+2) \times (+2) \times (+2) \times (+2) \times (+2) = +32$$

while

$$(-2) \times (-2) \times (-2) \times (-2) \times (-2) = -32$$

You will notice that we have not mentioned how to find the square root of a negative number. This is because it is impossible. As far as we know, there is no number multiplied by itself which can give a negative square. A negative number squared is always positive, and a positive number squared is always positive. The product $+2 \times (-2)$ is not a square because, if you notice the signs, we are not multiplying the same number by itself. We will learn more about this later in the course.

MULTIPLYING AND DIVIDING BY POWERS OF TEN

One of the greatest advantages of the decimal system is that in multiplying or dividing by 10 we simply move the decimal point. For example, if we multiply 237 by 10 the answer is 2370 because we move the imaginary decimal point, which is after the seven, one place to the right. To divide by 10, we move the decimal point one place to the left. Thus, 237 ÷ 10 is 23.7; in other words 10 goes into 237 twenty-three and 7/10 times.

You know that 2×2 is often written 2^2. Also, $2 \times 2 \times 2$ is written 2^3. Similarly 10×10 is written 10^2. Also, $10 \times 10 \times 10 = 10^3$, and $10 \times 10 \times 10 \times 10 = 10^4$ and so on. Thus, summarizing:

$10^0 = 1$
$10^1 = 10$
$10^2 = 10 \times 10 = 100$
$10^3 = 10 \times 10 \times 10 = 1000$
$10^4 = 10 \times 10 \times 10 \times 10 = 10{,}000$
$10^5 = 10 \times 10 \times 10 \times 10 \times 10 = 100{,}000$
$10^6 = 10 \times 10 \times 10 \times 10 \times 10 \times 10 = 1{,}000{,}000$

Why $10^0 = 1$ will be explained later in this section.

To multiply 237 by 10 we move the decimal point one place to the right. To multiply by 100, or 10^2, we move the decimal point two places to the right. To multiply by 1000, or 10^3, we move the decimal point three places to the right, etc.

To divide, we do the opposite. To divide by 100, or 10^2 we move the decimal point two places to the left, etc. Thus:

$237 \times 10 = 2370$
$237 \times 100 = 237 \times 10^2 = 23700$
$237 \times 1000 = 237 \times 10^3 = 237000$
$237 \div 10 = 23.7$
$237 \div 100 = 237 \div 10^2 = 2.37$
$237 \div 1000 = 237 \div 10^3 = .237$

Any number can be expressed in terms of a number between 1 and 10 times a power of 10. For example, 237 can be written as $2.37 \times 10 \times 10$. Rather than write the number out this way we usually write it 2.37×10^2. Similarly, 7648 can be written 7.648×10^3. Also, you can write 93486 as 9.3486×10^4.

Now consider the problem of multiplying 237×393. We rewrite 237 as 2.37×10^2, and 393 as 3.93×10^2. This breaks the problem down to:

$$2.37 \times 10^2 \times 3.93 \times 10^2$$

which we can regroup as:

$$2.37 \times 3.93 \times 10^2 \times 10^2$$

When two powers of 10 are multiplied together, you perform the multiplication simply by adding the exponents. In the expression 10^2, the exponent is 2. In 10^3 the exponent is 3. To multiply $10^2 \times 10^3$, you simply add the exponents and the problem becomes:

$$10^2 \times 10^3 = 10^{2+3} = 10^5$$

To multiply $10^3 \times 10^5$ proceed the same way:

$$10^3 \times 10^5 = 10^{3+5} = 10^8$$

If this seems somewhat confusing to you, or if you doubt that $10^3 \times 10^5 = 10^8$, you can write out 10^3 as $10 \times 10 \times 10$, and write out 10^5 as $10 \times 10 \times 10 \times 10 \times 10$, and then multiply them together, and you'll find that the answer is 10^8.

Now to get the rest of our answer we have to determine the value of $10^2 \times 10^2$. The term 10^2 is equal to 10×10, and therefore:

$$10^2 \times 10^2 = 10 \times 10 \times 10 \times 10$$

Since there are four tens, then $10^2 \times 10^2 = 10^4$ and our complete answer is:

$$9.31 \times 10^4$$

Another example is 767×839. Again, we write our factors in powers of 10, and so the problem becomes:

$$7.67 \times 8.39 \times 10^2 \times 10^2$$

We know from our previous problem that $10^2 \times 10^2$ is 10^4, so immediately it becomes:

$$7.67 \times 8.39 \times 10^4$$

Thus, our answer becomes:

$$64.4 \times 10^4$$

We can leave the answer in this form, but the usual procedure is to write the answer in terms of a number between 1 and 10. We can do this by writing our answer as:

$$6.44 \times 10^1 \times 10^4$$

There is no point in leaving the answer like this, because it is more complex than it need be, so we simply multiply $10^1 \times 10^4$ by adding the exponents to get:

$$6.44 \times 10^5$$

Multiplying Negative Numbers by Powers of Ten. When 347 is a positive number it can be written as:

$$347 = 3.47 \times 10^2$$

But what about -347? How would you write it? You might think you would write it as -3.47×-10^2. But if you go back to our rules of multiplication you'll see that $-10^2 = -10 \times -10 = 100$. Thus, there's no point in writing the minus sign in front of the ten unless we write it as $-(10)^2$. This means $-(10 \times 10) = -100$. Is this what we want? Let's look and see:

$$-3.47 \times -100 = 347$$

Obviously, we do not want to write our power of ten as $-(10)^2$. However,

$$-3.47 \times 100 = -347$$

so we can write -347 as -3.47×10^2. Similarly -47 is -4.7×10, and -5762 is -5.762×10^3. A negative number in powers of ten is written as a negative number between 1 and 10 times a power of ten.

The problem 347×-162 is written in powers of ten as:

$$3.47 \times 10^2 \times (-1.62) \times 10^2$$

The problem -114×-262 can be handled in the same way:

$$\begin{aligned} & -114 \times -262 \\ = & -1.14 \times 10^2 \times (-2.62) \times 10^2 \\ = & \ 2.99 \times 10^4 \end{aligned}$$

The 2.99 is positive, because a negative number times a negative number gives a positive product.

Division by Powers of Ten. You might wonder how we handle decimal numbers using this system. The number .147 is equal to $1.47 \div 10$. However, rather than leaving it in that form we write the number 1.47×10^{-1}. Notice the minus sign in front of the exponent 1. This indicates the number is divided by 10, or that the decimal point has been moved to the right one place. We write the number .0756 as 7.56×10^{-2}. This indicates that 7.56 is divided by 10^2 or 100.

Consider the problem of multiplying $.342 \times .266$. We rewrite the problem as:

$$3.42 \times 2.66 \times 10^{-1} \times 10^{-1}$$

The product 3.42×2.66 is approximately 9.10. Now to handle $10^{-1} \times 10^{-1}$, we simply add the exponents, and get 10^{-2}. Thus, our answer is 9.10×10^{-2}. If we want to express the number as a decimal number we simply divide it by 100, and we do this by moving the decimal point two places to the left. Notice that the exponent tells you how many places to move the decimal point. Thus,

$$9.10 \times 10^{-2} = .0910$$

Now consider the problem $.0187 \times -475$. We can write these numbers as powers of ten as follows:

$$1.87 \times 10^{-2} \times -4.75 \times 10^2$$

Notice in one case we have a negative exponent, in the other a negative number. There is no connection between the minus signs in front of the exponent and the number. They mean different things. The minus sign in front of the exponent means the number is divided by 10^2, but the entire number 1.87×10^{-2} is positive. The minus sign in front of 4.75

means the entire number, -4.75×10^2, is negative. Thus $1.87 \times 10^{-2} \times -4.75 \times 10^2$ is handled as two separate problems.

$$1.87 \times -4.75 = -8.88$$

and

$$10^{-2} \times 10^2 = 10^0 = 1$$

Therefore, our answer is −8.88.

You may wonder about 10^0 being equal to 1. You may think it should be zero. Let's see why it isn't.

We said earlier that when a number is multiplied by ten with a negative exponent, it indicates the number is to be divided by that power of ten. Therefore, $10^{-2} \times 10^2$ could be written as $10^2/10^2$, which equals 1. Also, $10^{-2} \times 10^2$ can be written as 10^0, because to multiply by powers of ten we add the exponents, and adding a +2 and a −2 gives us zero. Therefore, $10^0 = 1$. In fact, in the same way you can prove that any number to the zero power is equal to 1. Thus, $2^0 = 1$, $3^0 = 1$, $500^0 = 1$, $5{,}000{,}000^0 = 1$, and so on.

For now, we have all we need to know about signed number and their exponents and roots.

SELF-TEST QUESTIONS

(20) What is the rule for the addition of numbers with like signs?

(21) What is the rule for the addition of numbers with unlike signs?

(22) What is the rule for subtracting signed numbers?

(23) Add the following numbers:

−72, +13, −12, +57, +17, −6.

(24) Add the following:

(a) $\begin{array}{r} -16 \\ -\ 7 \\ \hline \end{array}$ (b) $\begin{array}{r} +13 \\ -\ 4 \\ \hline \end{array}$

(c) $\begin{array}{r} -22 \\ +48 \\ \hline \end{array}$ (d) $\begin{array}{r} -34 \\ +12 \\ \hline \end{array}$

(25) Subtract the following:

(a) $\begin{array}{r} -16 \\ -\ 7 \\ \hline \end{array}$ (b) $\begin{array}{r} +13 \\ -\ 4 \\ \hline \end{array}$

(c) $\begin{array}{r} -22 \\ +48 \\ \hline \end{array}$ (d) $\begin{array}{r} -34 \\ +12 \\ \hline \end{array}$

(26) State two rules which are used to determine the sign of the product when multiplying two signed numbers.

(27) State two rules used for determining the sign of the quotient when dividing signed numbers.

(28) Multiply:

(a) −6 by −7
(b) +9 by −2
(c) −11 by +17
(d) +12 by +3

(29) Divide:

(a) +60 by −15
(b) −144 by −6
(c) −153 by +51
(d) +516 by +12

(30) If −131 were raised to the sixth power, would the result be a positive or a negative number?

(31) Add the following:

(a) $\begin{array}{r} -\ 4 \\ -11 \\ +\ 7 \\ \hline \end{array}$ (b) $\begin{array}{r} +17 \\ -\ 6 \\ +13 \\ \hline \end{array}$

(c) $\begin{array}{r}-5\\-9\\\underline{-13}\end{array}$

(d) $\begin{array}{r}+21\\-41\\\underline{+20}\end{array}$

(32) Subtract the following:

(a) $\begin{array}{r}+81\\\underline{-57}\end{array}$

(b) $\begin{array}{r}-36\\\underline{-14}\end{array}$

(c) $\begin{array}{r}-42\\\underline{+17}\end{array}$

(d) $\begin{array}{r}+19\\\underline{+31}\end{array}$

(33) Multiply:

(a) $(+6) \times (-3) \times (-7) =$
(b) $(-4) \times (+10) \times (+3) =$
(c) $(-1) \times (+7) \times (+4) \times (+2) =$
(d) $(-2) \times (-3) \times (-4) \times (-5) =$

(34) Divide:

(a) −258 by −6
(b) +363 by −33
(c) −87 by +348
(d) +112 by −7

(35) Find the following:

(a) $(-2)^4 =$ (b) $(+2)^4 =$
(c) $(-3)^3 =$ (d) $(+3)^3 =$

(36) Do the following divisions and multiplications:

(a) $3247 \div 10^3$
(b) 7625×10^2
(c) $23 \div 10^4$
(d) $967 \div 10{,}000$
(e) $23 \times 100{,}000$
(f) $9327 \div 10^4$
(g) 82×10^2
(h) $.032 \div 10^2$
(i) $.0756 \times 10^3$

(37) Do the following divisions using powers of 10:

(a) $875 \div 326$
(b) $-526 \div 234$
(c) $.671 \div .0341$
(d) $-470 \div 621$
(e) $.234 \div 875$
(f) $1.46 \div 26.2$
(g) $735 \div .0234$
(h) $426 \div 621$
(i) $36.2 \div .0465$
(j) $9.21 \div -11.3$

Vectors

You learned in your technical lessons that an ac voltage actually consists of a series of different instantaneous values of voltage and that these different voltages all occur at specified times in the ac cycle. You also learned that the current forced through a complete electrical circuit by an ac voltage was likewise made up of a series of instantaneous values of current that occurred at specified times in a cycle. However, one of the most important factors that we must consider in dealing with ac circuits is that these peak ac voltages and peak ac currents do not necessarily occur at the same instant of time.

In your study of coils you found that the current actually lags the voltage by 90° in a purely inductive circuit. Conversely, you discovered that in a purely capacitive circuit the current leads the voltage by 90°. In fact, the only time that the instantaneous values of the current and voltage can be in phase with each other throughout the entire circuit is in a purely resistive circuit. Actually, most practical circuits contain some combination of resistance, inductance, and capacitance, and the phase relationship between the ac current and voltage is a result of the combined action of these effects.

Because of this difference in phase between the voltage and current in ac circuits, we cannot use ordinary arithmetic in our circuit calculations. In ordinary arithmetic we have only simple numbers or "scalars", as they are sometimes called, which we can use. The numbers or scalars can only indicate the size or the magnitude of the voltage or current quantities. They cannot, in any way that we know of, indicate the time difference or phase angle which we must also consider. However, through the use of what we call "vectors" and vector arithmetic, we can indicate both the size of the quantities and the times at which they occur. Actually, the vectors used in ac circuit calculations are not vectors at all, but are phasors. However, they are similar to vectors and are usually called vectors, so we will use that name instead. By using these vectors, we are able to perform any ac circuit calculation quite simply and accurately.

In this section of the lesson, you will learn about vectors and how they can be used in ac circuit calculations. You will apply many of the rules of ordinary arithmetic, square roots, signed numbers, and even some ratio and proportion in working with vectors. Vectors are extremely important in work with ac circuits, because without them any of the methods used for solving ac circuit calculations would be useless. They are all based on vector principles and you will discover later that many of the explanations for circuit characteristics are easier to understand if you use vectors.

DEFINITION OF A VECTOR

A vector is a straight line having a definite length and direction. Fig. 20 shows several different vectors, each with a certain length and direction. Although these vectors do not represent any particular values or functions, they are all true vectors and could be used for any

Fig. 20. Vectors showing definite length and direction.

number of purposes. Notice that each vector starts at a certain point and ends a certain distance away in a specific direction. The starting point of any vector is usually represented by a dot and is called the "tail" of the vector. The ending point of the vector is represented by an arrowhead and is called the "head" of the vector.

The distance between the head and tail of the vector is used to indicate or designate the magnitude of a quantity. The direction of the vector, from a common reference point or line, represents the second factor which we must consider. This second factor may be either "direction" or "time." For example, the vectors in Fig. 21 represent the flight of an airplane. They are drawn so that vector A represents a 125-mile flight to the south, while vector B represents a 150-mile flight to the east. The tail of vector A shows where the airplane started, and the head of vector B shows where the flight ended. The fact that the tail of vector B starts from the head of vector A, tells us that the airplane flew south first and then east. The arrow in the diagram shows us where north is and becomes the reference line from which the direction of the vectors may be determined. The notation "Scale: 1/4″ = 25 mi." tells how far the airplane traveled in each direction, because each quarter-inch of vector length is equal to 25 miles of travel. Thus, the vector diagram gives an accurate and descriptive picture of where the airplane went. As you can see, this is much more valuable than saying the airplane flew 275 miles.

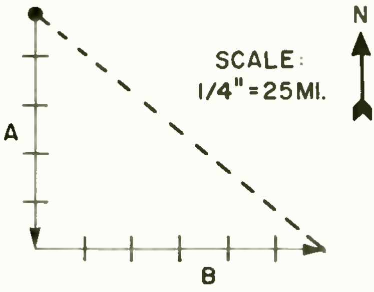


Fig. 21. Use of vectors to show results of motion.

Another thing about this vector diagram is that it can show how far the airplane actually went from the starting point. Notice in Fig. 21 that even though the airplane actually flew 275 miles, it did not end its flight 275 miles from the starting point. The head of vector B is not 275 miles away from the tail of vector A. Since the diagram is drawn to scale, you can measure this distance with a ruler, as shown by the dotted line in Fig. 21. If you do this carefully, you will find that it is just under 2 inches from the tail of A to the head of B. Since each quarter-inch on the diagram equals 25 miles, you know that the airplane ended its flight less than 200 miles from the starting point even though it flew 275 miles to get there.

Further, by comparing the direction of this dotted line with the reference arrow, you can determine the direction of the end of its flight from the starting point. If you do this, you can see that the flight ended approximately southeast of the starting point. Therefore, the vector diagram gives a complete picture of the airplane's flight as well as giving its progress away from the starting point.

Vectors in Electronics. In electronics work, we do not use vectors very often to indicate motion. Instead, we use the direction of vectors to indicate the time of an occurrence. For example, suppose that we have a series circuit containing a coil and a resistor as shown in Fig. 22. The ammeter in the circuit shows that there is an ac current of 5 amps flowing through the circuit and we know that the current in a series circuit is the same through any part of the circuit. Therefore, there is a current of 5 amps through the coil.

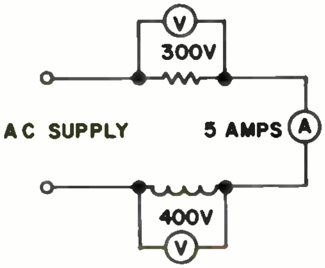


Fig. 22. AC circuit containing resistance and inductance.

The voltmeter across the resistor indicates 300 volts and the one across the coil indicates 400 volts. You know from your studies of ac circuits that these voltages across the coil and resistor do not occur at exactly the same instant of time. For example, if we were to draw a sine wave diagram of the ac current through the circuit, we might have a wave shape like the solid line in Fig. 23A. This sine wave rises from zero to a maximum of such a value that the effective value of the alternating current is 5 amperes. Using this ac sine wave as a reference point for time, and comparing the rise and fall of the voltage sine waves with it, we can actually see that the two voltages do not occur at the same instant.

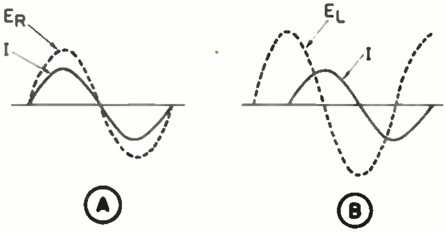


Fig. 23. Sine waves of voltage and current in a resistor (A), and a coil (B).

We know that in a purely resistive circuit the current and voltage actually rise and fall together. We say that they are in phase. Therefore, the voltage across the resistor, E_R, must rise and fall so that it will be maximum when the current is maximum. Further, the maximum value of this ac voltage must be large enough so that its effective value will be 300 volts, as measured by the voltmeter. Accordingly, if we were to draw a voltage sine wave for the voltage E_R, using the current sine wave as a time reference, we would have a wave shape like that shown by the dotted line in Fig. 23A.

On the other hand, the current and the voltage do not rise and fall together as far as the coil is concerned. The coil current actually lags the coil voltage by 90°. Therefore, we would draw their respective sine waves 90° out-of-phase, as shown in Fig. 23B, where the solid line, I, represents the coil current and the dotted line, E_L, represents the coil voltage. The current sine wave is the same sine wave that we used in Fig. 23A and occurs at exactly the same instant. The current is common throughout the circuit. The voltage wave, E_L, has a maximum value necessary to produce the effective value of 400 volts, as indicated by the voltmeter in Fig. 22.

Since the current sine waves in Figs. 23A and 23B represent the same current at the same instant of time, we can combine the two drawings as shown in Fig. 24. Here the one current sine wave, I, represents the common circuit current through both the coil and the resistor. The voltage wave, E_R, represents the sine wave voltage that gives the effective value of 300 volts across the resistor. The voltage wave, E_L, represents the sine wave that produces the effective value of 400 volts across the coil. It is easy to see from this drawing that the two voltages do not rise and fall together. They are 90° out-of-phase.

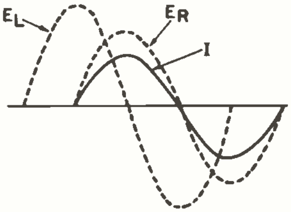


Fig. 24. Sine waves showing E_R lagging E_L.

Through the use of vectors, we are able to represent this difference in "time" between the two voltages and between the current and the coil voltage much more simply than by using sine waves. We do this by means of a rotating vector. As the vector rotates through 360°, the projection from the end of the vector traces out a sine curve. Looking at the current waveform in Fig. 23A, we see that the current is zero at the start of the cycle. This is represented by the vector shown in Fig. 25A. One-quarter of a cycle later, the current has reached its peak positive value. This is represented by rotating the vector 90° (one-quarter of a turn) to the position shown in Fig. 25B. At the end of another quarter-cycle, the current waveform will have gone through one-half of a cycle, and will be back to zero. This is represented by the vector shown in Fig. 25C. Here the vector has rotated through 180° (one-half turn). The vector in Fig. 25D represents the current waveform one quarter-cycle later when the current is at its peak negative value. The vector in Fig. 25E represents the current at the end of one complete cycle. Here the vector has rotated through 360° (one complete turn) and is back at the starting point.

Notice that we rotated the vector in Fig. 25 in a counterclockwise direction. Be sure to remember the direction of rotation; you'll need to know this to understand the vector diagrams in the rest of this lesson and in later lessons.

Now that you've seen how we use a rotating vector to show the current phase throughout a cycle, let's see how vectors can be used to show the phase relationship between the voltage and current across the resistor in Fig. 22, throughout a cycle.

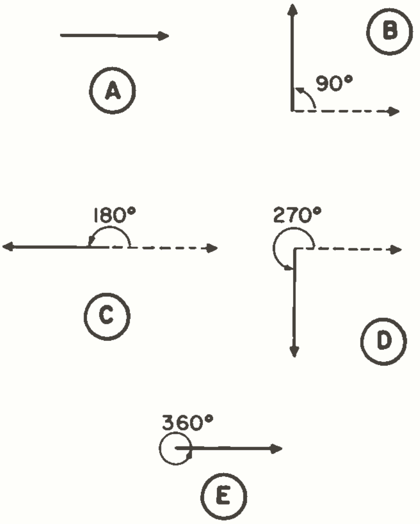


Fig. 25. A rotating vector showing one complete ac cycle.

At the start of the cycle at 0°, E_R and I are in phase. We show the phase relationship by drawing the two vectors, E_R and I, as shown in Fig. 26A. Notice that the vectors are drawn superimposed on each other because at the start of the cycle both the voltage and current are zero. One quarter-cycle later, the voltage and current have reached their maximum position values. This is shown by the vectors in Fig. 26B. Again the vectors are superimposed because the voltage and current are in phase - - they are both at their maximum values at the same instant, one quarter-cycle or 90° after they were both zero. In Fig. 26C we have shown the vectors at the end of one half-cycle, in Fig. 26D at the end of three quarter-cycles and in Fig. 26E at the end of a complete cycle.

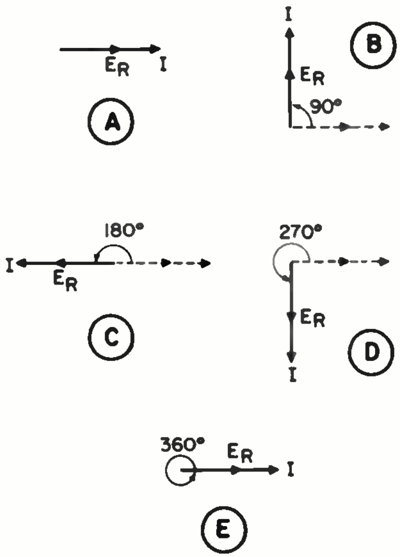


Fig. 26. Vector diagrams showing phase relationship between the voltage across and the current through a resistor, throughout a complete cycle.

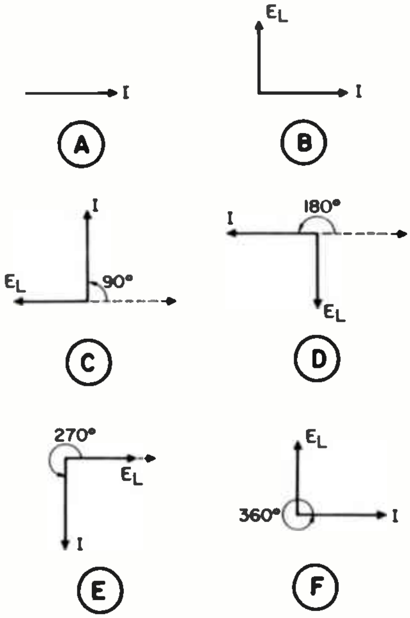


Fig. 27. Vector diagrams showing phase relationship between the voltage across and the current through a coil, throughout a complete cycle.

Now, let's see how vectors can be used to show the phase relation between the voltage across the coil and the current through it. Let's start with the current vector at zero representing the start of the current cycle, as shown in Fig. 27A. This vector is the same as the current vector in Fig. 25A. Now, to draw the vector representing the voltage across the coil we must consider the phase relationship. You will remember that the voltage across a coil leads the current by 90°. This is shown in Fig. 23B. Thus, if the current vector is drawn at zero, we must advance the voltage vector 90° (rotate it counterclockwise) as shown in Fig. 27B. Thus, the vectors in Fig. 27B show the phase of the voltage and current at the start of the current cycle.

One quarter-cycle later, both vectors will have rotated through 90°, as shown in Fig. 27C. At that point, the current is at its peak position value and the voltage has dropped to zero, as shown in Fig. 23. The vector diagram indicates this condition. A quarter-cycle later, when the current has gone through one half-cycle, the current will be zero again and the voltage will be at its peak negative value. This is shown in Fig. 23 and also in Fig. 27D by means of vectors. Fig. 27E shows the phases one quarter-cycle later when the voltage is back to zero and the current is at its peak negative value. Fig. 27F shows the voltage and current vectors at the end of a complete cycle.

Notice that throughout the illustrations in both Figs. 26 and 27, the phase relations remain constant. Fig. 26 shows the resistor voltage and current in phase through the entire cycle. Fig. 27 shows the coil voltage leading the current by 90° through the entire cycle.

In Fig. 24 we have shown the current, coil voltage, and resistor voltage on the same diagram. It does not matter whether we start working with the current, coil voltage, or resistor voltage in constructing our diagram, as long as we show the correct phase relationship. However, in circuits of this type the usual practice is to start by drawing the current vector I, as shown in Fig. 28A. Let's draw the vector to represent zero current at the start of the current cycle. We can draw the current vector any convenient length because we are not going to use it for anything other than a reference vector.

Now, let's draw a vector to represent the voltage across the resistor. In Fig. 22 we see that the voltage is 300 volts. Let's draw the vector to scale so the length of the vector represents 300 volts. If we use a scale of 1/2″ = 100 volts then the vector should be 1-1/2″ long. Since the voltage across the resistor is in phase with the current, the voltage vector is drawn superimposed on the current vector, as shown in Fig. 28B.

To draw the vector representing the coil voltage we first note, from Fig. 22, that the voltage is 400 volts. Therefore, using the scale of 1/2″ = 100 volts, the vector should be 2″ long. Since the coil voltage leads the current by 90°, we draw this vector as shown in Fig. 28C. Now we have a vector diagram showing the phase relationship between the current and the two voltages at the start of the current cycle. As a matter of fact, this diagram shows the phase difference between the coil voltage, the resistor voltage, and the current throughout the entire cycle because, as we saw from Figs. 26 and 27, these relationships did not change. The coil voltage always leads the resistor voltage and current by 90°.

We can use the vector diagram of Fig. 28C to determine the total voltage across the coil and the resistor. This is equal to the source voltage in Fig. 22. We do this by adding the vector representing the coil voltage to the vector representing the resistor voltage. Since we have drawn these vectors to scale, we should be able to scale the resulting vector to get the total voltage.

There are two ways of making this addition. The first way is to place the coil voltage vector at the end of the resistor voltage vector, like we did in Fig. 21, to determine how far the plane traveled. This addition is shown in Fig. 28D. Notice the resultant vector, E_T, which represents the total voltage that leads the current by a value somewhat less than 90°. This is what we might expect. In a circuit with pure resistance, the voltage and current will be in phase -- in other words the phase difference will be 0°. In a circuit with pure inductance, the volt-

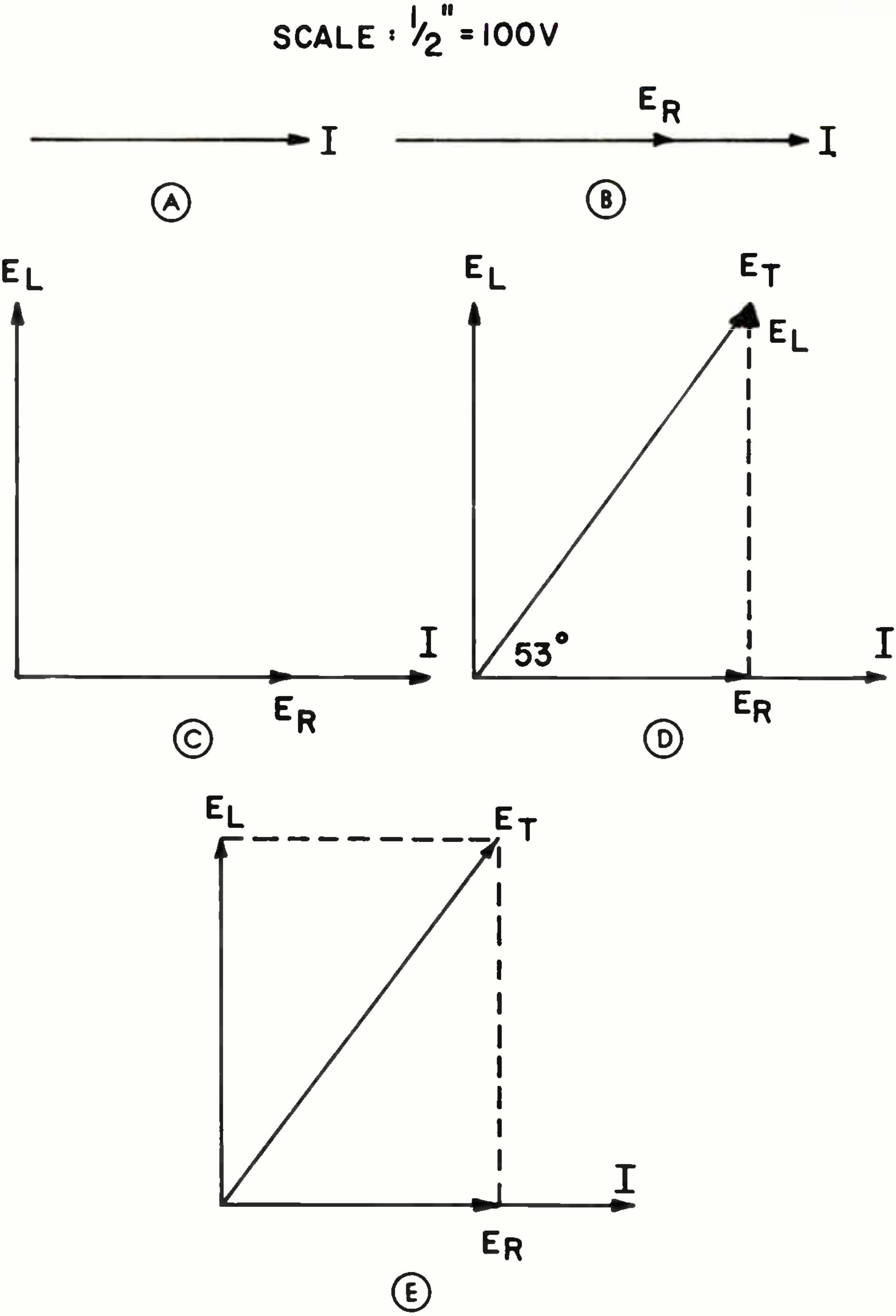


Fig. 28. Vector addition of resistor and coil voltages.

age leads the current by 90°. Thus, in a circuit with both resistance and inductance, we would expect both to influence the phase relationship between the voltage and current so that the phase difference will be somewhere between 0° and 90°. If you construct the diagram carefully and measure the angle between E_T and I, you will find that it is about 53°.

To determine the amplitude of E_T, measure the length of the vector. You will find it is 2-1/2" long. Since the scale used in constructing the diagram is 1/2" = 100 volts, the amplitude of E_T must be 500 volts.

The other method of adding the two vectors is shown in Fig. 28E. Here a dotted line is drawn from the end of vector E_R parallel to vector E_L. A second dotted line is drawn from the end of vector E_L parallel to E_R. The point where the two dotted lines meet locates the end of vector E_T. The angle between it and vector I will be the same when obtained by this method as it would be using the previously discussed method.

To really see the advantage of the vector method of representing these voltages, look at Fig. 29. Fig. 29A shows the sine waves of the two voltages and the current, and Fig. 29B shows how these sine waves can be added to get the total voltage. To do this, many instantaneous values must be added to enable you to plot the curve of E_T. This is tedious and, in addition, is not nearly as easy to evaluate as was Fig. 28D or Fig. 28E.

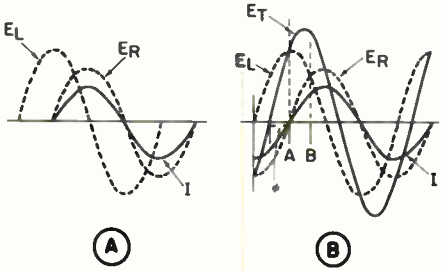


Fig. 29. Adding sine waves to obtain voltage total, E_T.

You might wonder why we started our construction of Fig. 28 by putting I in the 0° position. We did this simply because it was convenient. We could actually put I in any position. As long as we keep the correct position between I, E_R, and E_L, the value of E_T and the phase angle between it and I will be the same.

VECTOR ARITHMETIC

Now that we have seen what vectors are and how they can be used in electronics to represent size and phase or time for ac circuit calculations, let's learn more about handling them. Actually, the rules for working with vectors are quite simple and are similar to any arithmetic that involves signed numbers. The most important differences are learning to deal with the angles and establishing the qualifications for lead and lag.

To begin with, we have seen that any vector diagram must have a reference line so that the directions of the individual vectors can be established in accordance with a common reference for comparison. The reference we used in the preceding example was the current. The best type of reference to use when learning about vectors is a scale similar to the one we used when learning to deal with positive and negative numbers. In Fig. 30, we have drawn such a scale with a center reference point. All positive values extend to the right of the center and all negative values extend to the left.

Now suppose that we have two quantities representing the same direction or instant of time: one is +5 units long and

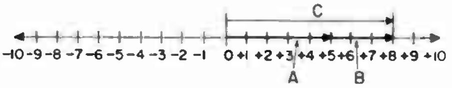


Fig. 30. Adding in-phase vectors.

the other +3 units long. In order to add them vectorially, we simply lay them out along the reference line (to scale) in the same direction, with the tail of one starting at the head of the other, as shown in Fig. 30. Vector A starts at the reference point, 0, and continues for five units. Vector B starts at the head of vector A and continues along the reference for three units. To add the two vectors, we simply draw a new vector, C from the tail of A to the head of B. Since A and B both point in the same direction, this new vector lays along the same line as A and B and is +8 units long. Therefore, we have a rule which states: ***The sum of two vectors extending in the same direction is a new vector equal to the combined length of the two vectors and pointing in the same direction.***

In Fig. 31, we have added two vectors [(–6) + (–3)] that point in the same direction, but both of them are negative so their direction is just opposite to those in Fig. 30. Therefore, their sum is a new vector that is –6 units long plus –3 units long which makes it –9 units long. Thus, as long as two or more vectors point in the same direction, regardless of what that direction is, their sum is a new vector, pointing in that direction, that is equal to the combined length of the individual vectors.

Another problem in working with vectors is when they point in opposite directions. This will often come up when two voltages or other circuit quantities are exactly 180° out-of-phase. For example, suppose we have two opposing voltages working against each other in an ac circuit. One of these has a peak value of 90 volts and the other a peak of 40 volts. The two are exactly out-of-phase at all times, so we can lay them out vectorially, as shown in Fig. 32, by using a scale of 1 unit equals 10 volts. Notice that since the two are 180° out-of-phase, one vector points from the reference point 0, along the reference line in one direction, while the other starts at the reference point and extends in the opposite direction.

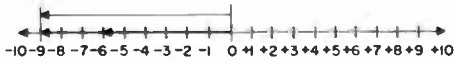


Fig. 31. Adding in-phase vectors.

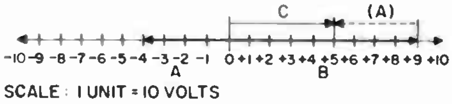


Fig. 32. Adding vectors 180° out-of-phase.

It does not make any difference which vector we use for which direction in this particular case. We know that each one changes sign during every cycle and we are just stopping the action at a particular time. No matter what we get for an answer, its sign will automatically change during the next alternation because we are working with ac. The thing that really does matter is that both vectors represent the same instant of time so that the 180° phase difference is represented by the vector directions.

To add these two vectors we must do the same thing that we did in other vector additions. We place the tail of one vector against the head of the other, being careful not to change the direction or length of the vector that we relocate. In this problem, we have drawn a dotted line from the head of the 90-volt vector B that is exactly the same length and points in the same direction as the 40-volt vector A. Notice that we have drawn the dotted line slightly above the reference line so that we can see it better. Now, we complete our addition by drawing a new vector, C, from the tail of the 90-volt vector. This new vector is 5 units, or 50 volts long, and points in the direction of the longest vector. Thus, we can see that the vector sum of the two out-of-phase voltages is a new vector, extending from the tail of one vector to the head of the other, after they have been properly joined (head to tail) for addition.

Representing Lead or Lag. As you can see, all the vector addition that we have considered so far follows the same basic pattern. We lay the vectors out to their proper scale length and orient them in their proper direction. Then, we lay them head to tail, being careful not to alter either their length or direction in the process, and draw a resultant vector, between the tail of the first vector and the head of the last, to represent their sum. The length of this resultant represents the magnitude of the vector sum, and its direction in relation to the reference line indicates the phase or time of the resultant quantity.

All vector computations follow these same basic rules. However, the problems that we have considered so far have dealt with vectors that are exactly in phase or exactly 180° out-of-phase. As you know, many of our problems in electronics deal with reactance calculations where the phase shift will be only 90°. Also, this reactance phase shift may be either 90° leading, in the case of the capacitance, or it may be 90° lagging in problems dealing with inductance. Accordingly, we must now consider what to do about laying out and computing vectors that are affected by reactance.

To do this let's go back to our basic idea of a phasor. A phasor is a rotating vector. We have shown that this vector rotates counterclockwise. Thus, if we start a vector at 0°, as in Fig. 33A, and rotate it 90° to represent one-quarter of a cycle, it will move to the position shown in Fig. 33B. The vector at B has passed through one-quarter of a cycle more than the one at A. Thus, vector B is leading vector A by 90°. The vector diagram in Fig. 33C shows how the voltage leads the current by 90° in a coil.

In Fig. 34 we have shown an example of a lagging voltage. We started with our current vector at A and then drew a second vector 90° behind it at B. Vector B is following vector A by 90°. A complete vector diagram showing how the current leads the voltage in a capacitor is shown in Fig. 34C.

You might think that since the two

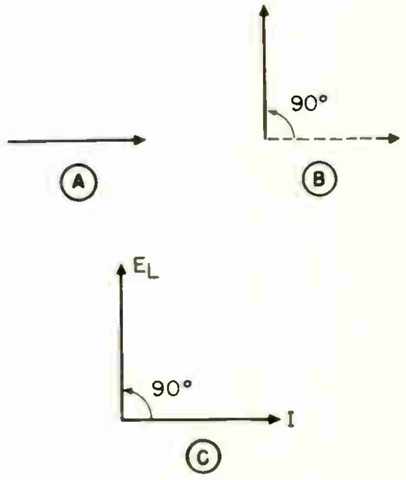


Fig. 33. Vector diagrams showing 90° phase shift where the voltage leads the current.

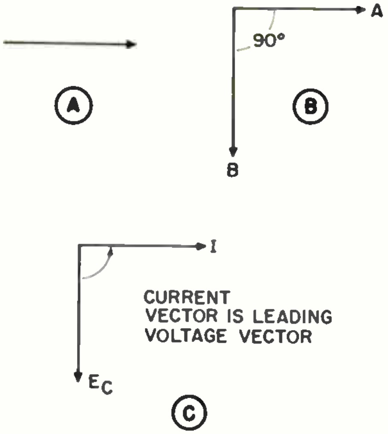


Fig. 34. Vector diagrams showing a 90° phase shift where the voltage lags the current.

vectors are rotating counterclockwise, the voltage vector is leading the current by 270°. Since the voltage is lagging one current cycle by 90°, it will indeed be leading the following current cycle by 270°. However, it is the 90° phase difference we are interested in.

Now it is fairly easy to see that, if we consider our discussions of vectors up to this point, we can call the right-hand end of the scale the "in-phase reference line." Likewise, the end of the horizontal line extending to the left of the center towards 180° can be called the "180° out-of-phase reference line." If we do this, all vectors parallel to the horizontal reference and pointing to the right will be in-phase vectors, and those pointing to the left will be 180° out-of-phase. Thus, our horizontal line, divided in the center in this way, can represent a phase shift or time lag of 180°, depending on whether we point our vectors from the center to the right of 0° or from the center to the left of 180°.

The vertical line represents a phase shift of 90°. Since our vector rotates counterclockwise, the vector representing the voltage in Fig. 33C is leading the current vector by 90°. It's not always necessary or even advisable to place the current vector at 0°. However, regardless of how we start the diagram and what we place on the 0° axis, all voltages or current leading the reference value are shown rotated in a ***counterclockwise*** direction. Voltages or currents lagging the reference value are shown in a ***clockwise*** direction. Any voltage or current can be taken as our reference value, but in most series circuits it is easiest to use the current as a reference.

Sometimes we may want to construct an impedance diagram of resistance, and inductive or capacitive reactance. You might wonder if one of these reactive elements should be drawn above or below the reference line. The rule is to draw inductive reactance above and capacitive reactance below. Inductive reactance is considered positive and capacitive reactance negative. You'll see later, when you study the j-operator, that this is necessary in order to get the currents to have the correct phase. Thus, if we consider our reference line extending from the center right towards 0°, as our current reference line in ac circuit problems, our inductive reactance (voltage leading current) values will go above the reference and our capacitive reactance (voltage lagging current) values will go below the reference. Another thing that will help you to remember this rule is to notice that vectors are always considered to rotate counterclockwise from zero.

Also notice that the 90° head point from the center can also be considered to lag the 0° reference line by 270°. It doesn't make any particular difference which way you think of it. The important thing is to make sure that when you construct a scale like this and use the current as the reference vector, you should remember:

1. Right from center: in phase I, R, or E_R.
2. Left from center: 180° out-of-phase.
3. Straight up from center: 90° lead, X_L or E_L.
4. Straight down from center: 90° lag, X_C or E_C.

VECTOR CALCULATIONS

Now that we have discussed some of the basic rules and principles for laying out vectors and computing with them, we need to gain a little practice to become thoroughly familiar with this type of computation. We considered a problem dealing with a coil and a resistor a little earlier. Now, let's consider a circuit containing a resistor and capacitor in series like the one shown in Fig. 35A. In this circuit we are told the capacitor voltage and the resistor voltage and are asked to find the supply voltage, E_T, and the phase angle, θ.

In order to do this, we first lay out the current vector as the reference vector because the current in the circuit, I, is the same in all parts of the circuit. Using the horizontal line extending to the right toward 0° to represent the current, as we have learned to do, completes our preliminary setup for the problem, as shown in Fig. 35B. Notice that we do not have the value of this current. It is not needed to work the problem. We are only using I as a reference line from which to indicate our voltage-phase relationships. Its value is not important. Its position as the common reference is what concerns us here.

Using the scale of 1/2″ = 100V, we can lay out the voltage vector, E_R, to scale along the reference line to show that the voltage across the resistor is in phase with the current through it. We call this voltage the in-phase component of the total voltage. The vector diagram of this stage is shown in Fig. 35C. Then we can lay out the voltage vector, E_C, to scale 90° behind the reference current because I will be leading it by 90°. The diagram at this point is shown in Fig. 35D. To add these two vectors, we can move one of them so that the two are head to tail, as shown by the dotted vector, E_C, in Fig. 35E and then draw in E_T, the total voltage. Notice that we are careful to construct the dotted vector, E_C, so that its length and direction are not changed. We can also get E_T by drawing a line parallel to E_R from the end of E_C, and a second line parallel to E_C from the end of E_R. Where the two lines meet locates the end of E_T, as shown in Fig. 35F.

Now, we can draw the resultant vector, E_T, that represents the vector sum of the two quantities. If we measure E_T carefully and our other vectors are to scale, we will find that E_T is 2-1/8″ long. Since 1/2″ = 100V, 1″ must equal 200 volts, and 2″ must equal 400 volts. Now, since 1/8″ is equal to 1/4 of 1/2″, 1/8″ is equal to 25 volts. Accordingly, our E_T vector, which is 2-1/8″ long, must equal 400 + 25 or 425 volts.

We are also asked to find the phase angle, θ, for our supply voltage. We can do this by using a protractor which measures angles. We will find that the angle between E_T and the reference I is 45°. As a matter of fact, we can estimate that E_T lies about halfway between E_C and I, which are 90° apart, so E_T must be approximately 45° out-of-phase with the current. Thus, through the use of vectors, we have determined that E_T is 425 volts and is 45° out-of-phase with the current. Since E_T is below the reference I, the

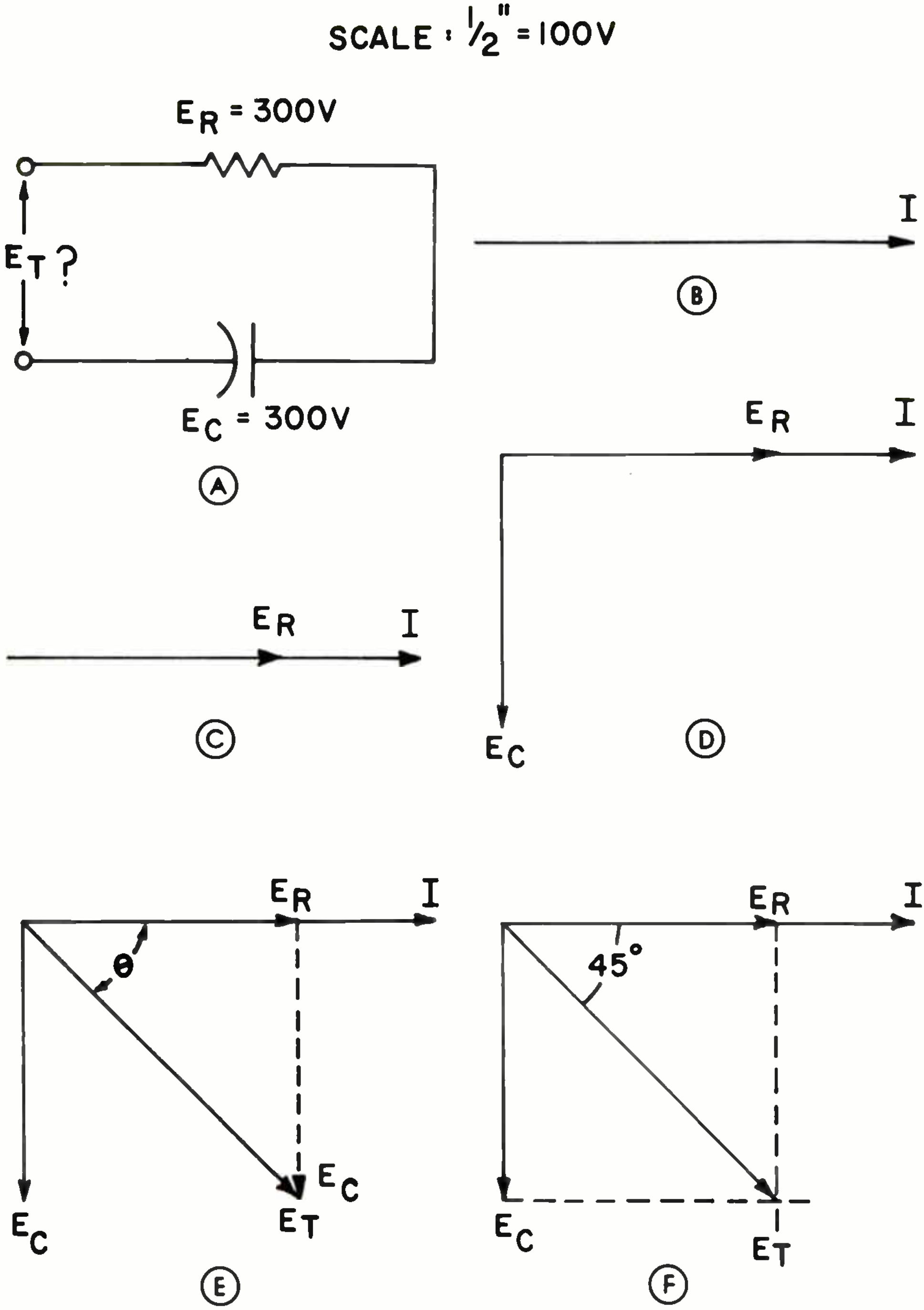


Fig. 35. Vector addition of the voltage E_R and E_C in the circuit at (A) shown in detail.

current must *lead* the voltage (or the voltage lags the current, whichever you prefer) by 45°.

Before we leave this circuit, let's consider one other thing. In converting our length of E_T of 2-1/8" to 425 volts, we went through a series of steps. Ratio and proportion would have saved us a lot of time. For example, we could have set up two ratios as follows:

$$\frac{\frac{1}{2}''}{2\frac{1}{8}''} \quad \text{and} \quad \frac{100\text{V}}{E_T}$$

Now our proportion:

$$\frac{\frac{1}{2}''}{2\frac{1}{8}''} = \frac{100\text{V}}{E_T} \quad \text{or}$$

$$\frac{\frac{1}{2}''}{\frac{17}{8}''} = \frac{100\text{V}}{E_T}$$

Now cross-multiplying, we have:

$$\frac{17}{8} \times 100 = \frac{1}{2} \times E_T$$

$$\frac{1700}{8} = \frac{E_T}{2}$$

and then:

$$8 \times E_T = 1700 \times 2$$
$$8E_T = 3400$$
$$E_T = \frac{3400}{8} = 425 \text{ volts}$$

This is just another example of a good use for ratio and proportion.

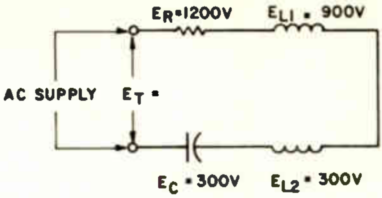


Fig. 36. Finding E_T in a simple series ac circuit containing R, L, and C.

In Fig. 36, we have shown a more difficult problem. Here we have a resistor, two coils, and a capacitor in series with each other. Let's see how we would handle the problem of finding the total voltage for this circuit vectorially.

First, we lay out our vector reference scale and call the horizontal line, which is from center to 0°, the current reference. This is shown in Fig. 37. Then we can draw in the voltage vector E_R superimposed on I to show the two in phase. Since E_R is 1200 volts, we used a scale of 1/4" = 100 volts, instead of 1/2" = 100 volts as before, in order to keep the diagram a reasonable size in the book. If you try drawing this diagram you can use a scale of 1/2" = 100 volts if you wish. Then E_R would be twice as long. Next, we draw vector E_{L1} leading I by 90°. This vector represents 900 volts. Using the scale of 1/4" = 100 volts, we make it 9 X 1/4" = 9/4 = 2-1/4" long.

The next step is to add the vector E_{L2} to the diagram. Since this voltage also leads I by 90°, we draw E_{L2} starting at the head of E_{L1} to add these two in-phase voltages. E_{L2} is made 3/4" long to represent 300 volts.

The next vector we draw is E_C. Since this represents 300 volts we know it should be 3/4" long. Also, since it represents a voltage across a capacitor, we know it will lag I by 90°. The position of this vector is shown on the diagram. Notice that it is 180° out-of-phase with

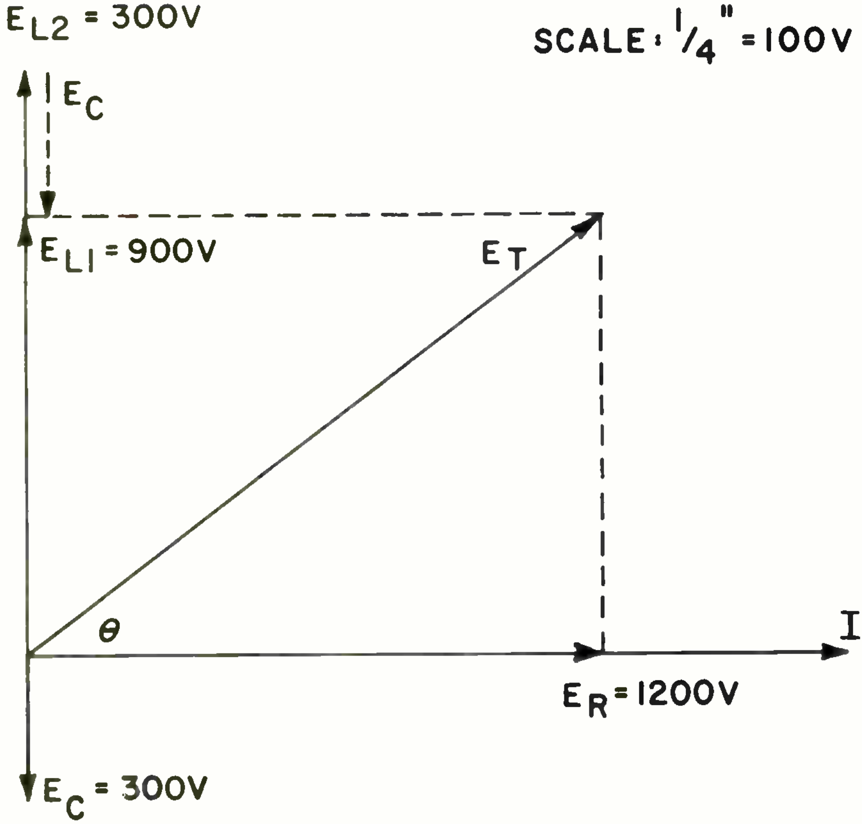


Fig. 37. Vector solution of multiple reactance circuit.

E_{L1} and E_{L2}. We now add this vector to the sum of E_{L1} and E_{L2} following the same procedure as shown in Fig. 32. We move vector E_C to the head of E_{L2} as shown by the dotted line. Then the head of E_C represents the total reactive voltage. We have shown E_C dotted and slightly to one side of E_{L2} so you can see it; actually it should be superimposed on E_{L2}.

To complete the vector diagram and get E_T, we draw a line parallel to vector E_R from the end of the vector representing the sum of E_{L1} + E_{L2} + E_C. Then we draw a second line parallel to the E_{L1} vector from the end of E_R. The point where these two lines intersect locates the end of E_T. Now we can draw vector E_T to represent the sum of our reactance and resistance vectors and carefully measure it. We find that it is exactly 3-3/4" long. Now, by setting the ratios and proportion between our scale values and our measurements, we can convert our vector measurements to volts as follows:

$$\frac{\frac{1}{4}''}{3\frac{3}{4}''} = \frac{100}{E_T}$$

$$\frac{1}{4}'' \times E_T = 3\frac{3}{4}'' \times 100$$

$$\frac{E_T}{4} = \frac{15}{4} \times 100$$

$$\frac{E_T}{4} = \frac{1500}{4}$$

$$4E_T = 4 \times 1500$$

$$E_T = 1500 \text{ volts}$$

We can then determine the value of θ by measuring it: $\theta = 36\text{-}1/2^\circ$.

So far, in working with vectors, we have considered only the addition of vectors to find a total. We can also break down a given resultant vector to find some of its components. In other words, if we have E_T, we can find E_R and the total circuit reactance voltage. This process is important when working with parallel ac circuits, so let's see how it is done.

Suppose we are given a statement regarding the voltage of a circuit as follows: "The voltage applied to a series circuit is equal to 140 volts and it leads the current by a phase angle of 45°. What is the value of the resistance in the circuit if the current is 5 amperes?" Although this might seem difficult at first glance, it is really quite easy to solve. First, let's see what we know about the voltage.

We can see that it leads the current (or that the current lags the voltage) and, therefore, the total reactance in the circuit must be inductive. We know the phase angle is 45° and that the voltage value is 140 volts. With this information we can lay out our standard reference diagram for vector solutions and construct a vector that represents the total voltage applied. Using a scale of 1/4″ = 20 volts, our total voltage vector, E_T, can be laid out to scale as shown in Fig. 38. We

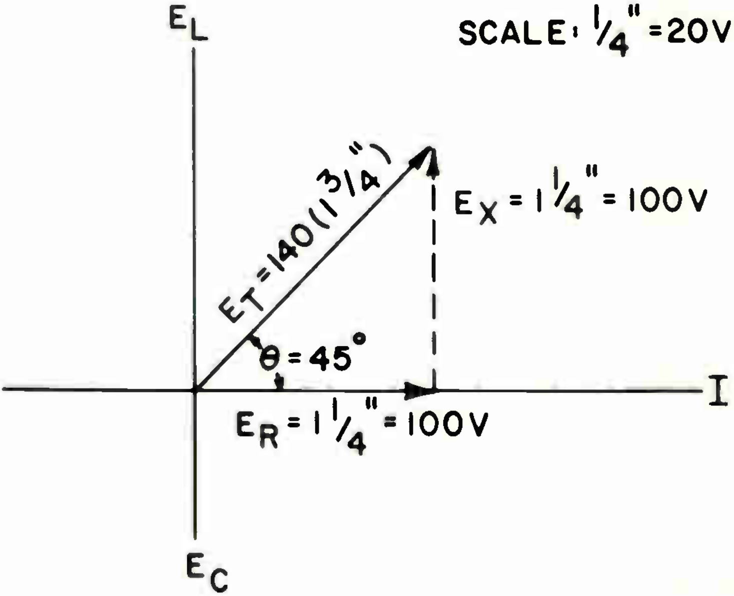


Fig. 38. Breaking a vector down into two components.

have drawn this vector above the reference line I, at the phase angle of 45°, to show that it is inductive and leads the current. Now this vector, E_T, is a resultant vector and must be made up of at least two component vectors; one resistive, and one reactive. Any vector that is not out-of-phase with the reference by some multiple of 90° can always be broken down into at least two components that are at right angles to each other. Because of this rule, we can separate the vector E_T into two component vectors.

Doing this, we find that in the circuit the reactive component, E_X, is equal to 100 volts and the resistive component, E_R, is also equal to 100 volts. Now that we have the resistive voltage drop of 100 volts, it is easy to find the resistance. We know that it is a series circuit and, therefore, the current is common. Accordingly,

$$R = \frac{E_R}{I} = \frac{100}{5} = 20 \text{ ohms}$$

Thus, by breaking down the vector value of applied voltage into its two components, we are able to determine quite a lot about the circuit. You will find that

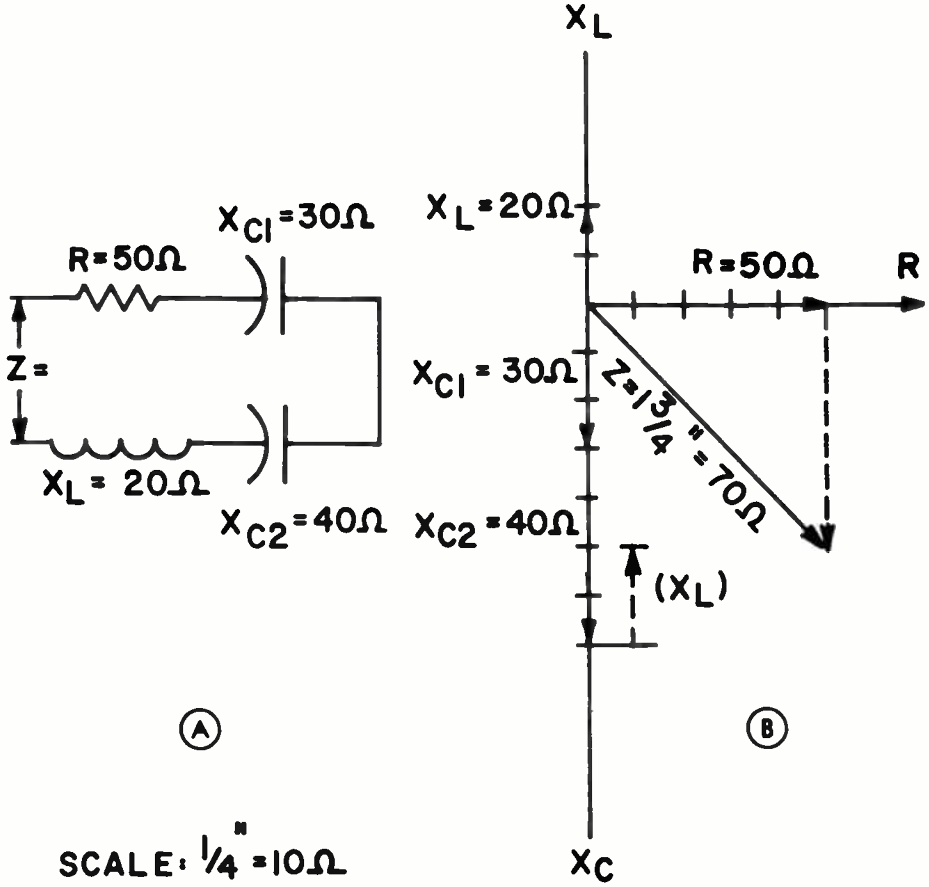


Fig. 39. Solving for impedance with vectors.

this is a very valuable process in your electronics work.

Up until now, we have been working primarily with the voltages in a circuit. We can use our vector diagrams and computation methods to find the impedance of a circuit. For example, suppose we wanted to find the total impedance of the circuit shown in Fig. 39A. We would simply lay out our vector diagram and add the component vectors just as we did when we were working with voltage, as shown in Fig. 39B. Notice that we use R as the reference line because it represents the in-phase component of the impedance Z. You should have no trouble following the solution of this simple vectorial computation.

PYTHAGOREAN THEOREM FOR VECTOR SOLUTIONS

You will remember that earlier in this lesson and in your technical lessons, we mentioned that we could use formulas instead of vectors for ac circuit solutions. One of the most familiar is the formula for impedance which is,

$$Z = \sqrt{R^2 + X^2}$$

This formula is really just a mathematical solution of a vector diagram. By using it, we involve ourselves in the problem of finding a square root, but it is often much more desirable and usually more accurate than solving vectors by measurement. In measuring vectors for the solution of vector diagrams, we need to take care in laying out the diagrams, and measuring the angles and lengths of the vectors.

In working with the formulas, we are given a method of solving for the lengths of the vectors, but not the angles. Since the formula allows us to use a mathematical solution for the length of the vectors in vector diagrams, it eliminates the need for the accuracy of layout and measurement. Let's look at a typical vector diagram and see how it is possible to consider the formula $Z = \sqrt{R^2 + X^2}$ as the mathematical solution.

In Fig. 40A, we have laid out the solution of a typical vector diagram for finding the impedance of an ac circuit. The vector representing R, the dotted vector representing X_L, and the resultant vector Z, representing the impedance of the circuit, forms a three-sided, completely enclosed figure. Such a three-sided figure, as you probably know, is called a triangle. However, this is a special type of triangle, called a right triangle. Any triangle that contains one angle that is equal to 90°, such as the angle between vectors X_L and R, is a right triangle, no matter what the other two angles or the lengths of the sides may be. Any triangles involved in vector solutions for ac circuits will also be right triangles, because two of the sides must be 90° displaced from each other.

It is important that you realize this and understand it, since many of the laws for ac circuit solutions depend on this fact. In Fig. 40B, we have drawn the triangle of Fig. 40A, leaving out the arrowheads and values so that we can show you a very important fact about all right triangles. First of all, notice that we have given names to the sides of our right triangle in Fig. 40B. The longest side, or the side opposite the right angle, is always called the hypotenuse. The other two sides are simply known as legs or sides.

Many years ago, a mathematician named Pythagoras discovered a very interesting fact about right triangles. He discovered that if you squared each side

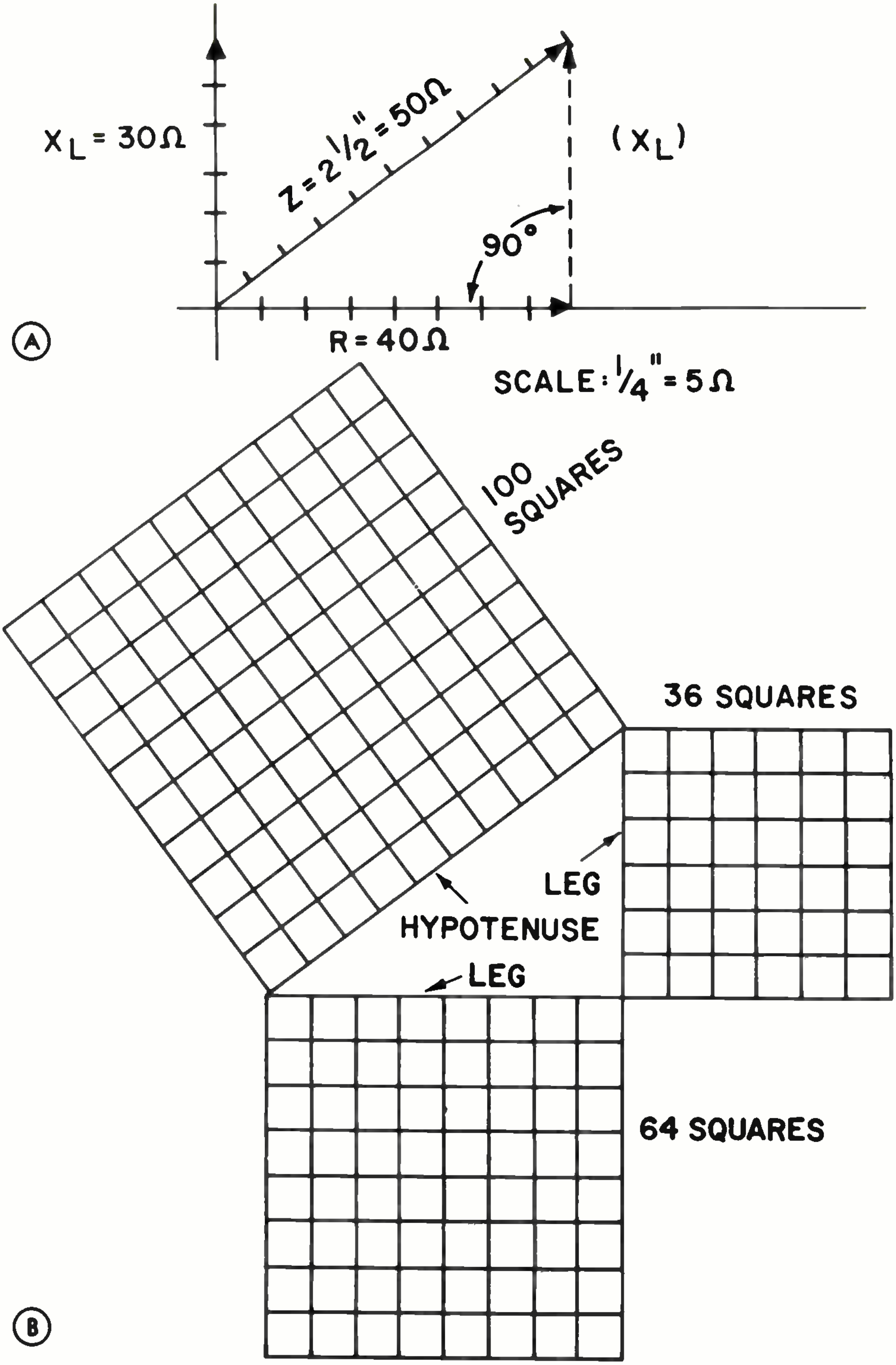


Fig. 40. The derivation of the Pythagorean Theorem.

of the right triangle and filled in all the squares in between as we have shown, the sum of all the squares (created by squaring the two legs) is exactly equal to the number of squares created by squaring the hypotenuse. You can actually prove this to yourself by counting all the squares in the two legs. You will find that there are 64 squares in the bottom leg and 36 squares in the vertical leg. The sum of 64 and 36 is, of course, 100. Now, if you count all the squares made by squaring the hypotenuse, you will find that there are also exactly 100. Thus, we have the theorem which Pythagoras discovered:

The square of the hypotenuse of any right triangle is equal to the sum of the squares of the other two sides.

If we apply this theorem to our vector diagram in Fig. 40A, we have:

$$Z^2 = R^2 + (X_L)^2$$

Then, by substituting our values, we have:

$$\begin{aligned} Z^2 &= 40^2 + 30^2 \\ &= 1600 + 900 = 2500 \end{aligned}$$

Then, if $Z^2 = 2500$, $Z = \sqrt{2500} = 50$. You will notice that this is the same answer we obtained by measurement. You will also notice that our statement $Z^2 = R^2 + X_L{}^2$ is the same as one of our formulas; $Z = \sqrt{R^2 + X_L{}^2}$. We usually use the general formula;

$$Z = \sqrt{R^2 + [X_L + (-X_C)]^2}$$

because we always find our total reactive component, X, before we find our squares. In this way, we can solve for any right angle vector diagram without using a measurement solution.

SELF-TEST QUESTIONS

(38) What is a vector?

(39) Draw a simple vector diagram which shows the phase relationship between the voltage across and the current through a coil.

(40) A coil and resistor are connected in series across an ac generator. The voltage drop across the coil is 10 volts and the drop across the resistor is 20 volts. Draw a vector diagram which shows the amplitude and phase relationship of the two voltages.

(41) Find the total voltage from the generator using the vector diagram in Question 40.

(42) Draw a vector diagram which shows the phase relationship between the voltage across and the current through a capacitor.

(43) A coil, resistor, and capacitor are connected in series across an ac generator. The coil drops 12.5 volts, the resistor 15 volts, and the capacitor 7.5 volts. Draw a vector diagram showing amplitude and phase relationship of the 3 voltages.

(44) Find the total voltage supplied by the generator described in Question 43.

(45) State the Pythagorean Theorem.

(46) What is a right triangle?

(47) What quantity is represented by the hypotenuse of a right triangle which has one side representing resistance and the other side representing reactance?

Circuit Calculations

In this lesson and in your previous lessons you have learned many of the important facts concerning ac circuits. You have also studied some of the mathematical procedures that can be used in considering these facts in ac circuit calculations. Although you may feel that at the present time you have mastered all this information, it is quite possible that you will forget many of the details. One of the best ways to prevent forgetting this information and to insure that you really do understand it thoroughly is to get some practice using it.

Therefore, at the end of this section we will present several typical circuit problems and ask you to solve them. Remember that many times it may be necessary to solve for intermediate values in order to obtain the necessary factors for use in finding the answers. If you have learned and understood the mathematics and electronics that you have studied so far, you should be able to obtain all the answers without too much difficulty.

Most of the information in this lesson parallels the technical lessons from 6 through 9. Therefore, the problems will deal mainly with the formulas and data covered in these same technical lessons. If you have any real difficulty with the solutions of these problems, it will be a good idea to review the appropriate subjects in other lessons that you have had. Remember, only by working out the solutions of these problems will you be sure that you have thoroughly understood the material presented. It is very important for you to do this before you continue with your remaining lessons.

To help refresh your memory and prevent your having to look up too much information regarding these problems, we have listed some of the more important formulas that you have studied. If you find that you do not thoroughly remember and understand these useful and common formulas, it will be a good idea to review them before you start working the problems.

Inductance of coils in series:

$$L_T = L_1 + L_2 \pm 2M$$

Inductance of coils in parallel:

$$L_T = \frac{L_1 \times L_2}{L_1 + L_2}$$

Inductive reactance:

$$X_L = 2\pi fL$$

(f = Hertz, L = henrys)

Q of a coil:

$$Q = \frac{X_L}{R}$$

Capacitance of capacitors in series:

$$C = \frac{C_1 \times C_2}{C_1 + C_2}$$

Capacitance of capacitors in parallel:

$$C = C_1 + C_2 + C_3$$

Capacitive reactance:

$$X_C = \frac{1}{2\pi fC} \text{ or}$$

$$X_C = \frac{159000}{fC}$$

where f is in Hertz and C is in mfd.

Ohm's law for ac circuits:

$$E = I \times Z$$

Impedance in ac circuits:

$$Z = \sqrt{R^2 + X^2}$$

Total voltage in ac circuits:

$$E_T = \sqrt{E_R{}^2 + E_X{}^2}$$

Resonant frequency:

$$f = \frac{1}{2\pi\sqrt{L \times C}}$$

or

$$f = \frac{.159}{\sqrt{L \times C}}$$

Turns ratio of transformers:

$$\frac{N_1}{N_2} = \frac{E_1}{E_2}$$

$$\frac{N_1}{N_2} = \frac{I_2}{I_1}$$

$$\frac{N_1}{N_2} = \sqrt{\frac{Z_1}{Z_2}}$$

EXAMPLES

Study the following examples carefully. They are purposely difficult to give you practice and show you how to get the correct answers in an orderly manner. Break down a problem into smaller parts and solve for each part step by step. You will note that it is necessary to find a quantity not asked for but required before you can get the final answer. Review of these examples, although quite advanced for you at this time, will give you the confidence to tackle the exercise at the end of this section. Do not be discouraged should you not get the right answer on the first try.

Be sure you have all quantities in the correct units. If you are asked to find power in a circuit and are given the voltage in volts and the current in milliamps, you must convert the current to amperes by moving the decimal point three places to the left. When you need to find either inductive or capacitive reactance, be sure that you have frequency in Hertz and inductance in henrys or capacitance in farads. To convert microhenrys to henrys or microfarads to farads, move the decimal point six places to the left.

Example 1: Find the current in a series circuit consisting of a 150-ohm resistor, a 292 millihenry coil, and a 7 microfarad capacitor if the line voltage is 120 volts and the line frequency is 150 Hertz.

Solution: To find the current in an ac circuit, you divide the voltage by the impedance of the circuit. This is Ohm's Law for ac circuits.

$$I = \frac{E}{Z}$$

We know E, but do not know Z so we must find Z.

$$Z = \sqrt{R^2 + [X_L + (-X_C)]^2}$$

We know R, but we do not know X_C or X_L so we must find these values.

$$X_L = 2\pi fL$$

and

$$X_C = \frac{1}{2\pi fC}$$

Since we know f, L, and C we can find X_L and X_C. Then we can get Z, and Z is used to find I. Therefore, our first steps in the problem are to find X_L and X_C. Let's do that now:

$$X_L = 2\pi fL$$

$2\pi = 6.28$, f = 150 Hertz and L = 292 millihenrys.

To use our formula, f must be in Hertz, which it is, and L must be in henrys. So we must convert 292 millihenrys to henrys by moving the decimal three places to the left.

Thus, 292 millihenrys = .292 henrys. Now $X_L = 6.28 \times 150 \times .292$.

$$\begin{array}{r} 6.28 \\ \underline{1\,50} \\ 314\,00 \\ \underline{628} \\ 942.\,00 \end{array}$$

$$\begin{array}{r} 942 \\ \underline{.292} \\ 1884 \\ 8478 \\ \underline{1884} \\ 275.064 \end{array}$$

Thus, X_L = 275.064 ohms, which we can round off to 275 ohms.

Now let's find X_C using the formula

$$X_C = \frac{1}{2\pi fC}$$

Again $2\pi = 6.28$, f = 150 Hertz and C = 7 microfarads. C must be in farads so we move the decimal six places to the left.

Thus, 7 microfarads = .000007 farad.

$$X_C = \frac{1}{6.28 \times 150 \times .000007}$$

6.28 × 150 = 942 (we did this when we were finding X_L).

$$\begin{array}{r} 942 \\ \underline{.000007} \\ .006594 \end{array}$$

Now dividing $.006594 \overline{)\,1}$

$$\begin{array}{r} 151.6 \\ 6594\overline{)1000000.} \\ \underline{6594} \\ 34060 \\ \underline{32970} \\ 10900 \\ \underline{6594} \\ 43060 \end{array}$$

Thus, X_C = 151.6 ohms, which we round off to 152 ohms. Now that we know R, X_L, and X_C, we can get Z using

$$Z = \sqrt{R^2 + [X_L + (-X_C)]^2}$$

To add X_L and X_C we must remember they are opposite reactances. X_L is positive and X_C is negative. Thus, when we add we have 275 + (−152) so, because of the negative number, we subtract

$$\begin{array}{r} 275 \\ -152 \\ \hline 123 \end{array}$$

Therefore, $X_L + X_C = 123$ ohms.

Now, squaring 123 we get

$$\begin{array}{r} 123 \\ 123 \\ \hline 369 \\ 246 \\ 123 \\ \hline 15129 \end{array}$$

And squaring R we get

$$\begin{array}{r} 150 \\ 150 \\ \hline 7500 \\ 15 \\ \hline 22500 \end{array}$$

Now, adding $R^2 + [X_L + (-X_C)]^2$

$$\begin{array}{r} 22500 \\ 15129 \\ \hline 37629 \end{array}$$

To find Z we must take the square root of 37629.

$$\begin{array}{rl} & 1\ \ 9\ \ 3.\ 9 \\ & \sqrt{3,76,29.00} \\ & 1 \\ 29 & \overline{\big|\,276} \\ & 261 \\ 383 & \overline{\big|\,1529} \\ & 1149 \\ 3869 & \overline{\big|\,38000} \\ & 34821 \end{array}$$

Thus, Z is 193.9 ohms, which we can round off to 194 ohms.

Now, to find I we use

$$I = \frac{E}{Z}$$

$$I = \frac{120}{194}$$

$$\begin{array}{r} .618 \\ 194\overline{\big)120.0} \\ 1164 \\ \hline 360 \\ 194 \\ \hline 1660 \\ 1552 \\ \hline 108 \end{array}$$

The line current is .618 amps. Notice how we solved this problem. We worked backwards to find what we had to determine in order to get the required answer and then began by evaluating the terms needed to get the final solution.

Example 2: Find the voltage across the inductance in a series circuit having an inductive reactance of 4 ohms, a capacitive reactance of 12 ohms and a resistance of 6 ohms, if the voltage applied to the circuit is 50 volts at 60 Hertz.

Solution: To find the voltage across the coil we need to know the current flowing in the circuit. Then we can use the formula

$$E_L = I \times X_L$$

To get I, we need the impedance. Then we can use

$$I = \frac{E}{Z}$$

We start by getting Z.

$$Z = \sqrt{R^2 + [X_L + (-X_C)]^2}$$

$X_L = 4$ and $X_C = -12$ so we have

$$\begin{array}{r} 4 \\ +(-12) \\ \hline -\ 8 \end{array}$$

Thus, $Z = \sqrt{6^2 + (-8)^2}$.

Remember the $(-8)^2$ is $(-8) \times (-8)$ and your rules for multiplying signed numbers tell you that $(-8) \times (-8) = 64$

Therefore,

$$\begin{aligned} Z &= \sqrt{36 + 64} \\ &= \sqrt{100} \\ &= 10 \text{ ohms} \end{aligned}$$

Thus, $I = 50/10 = 5$ amps and the voltage across the coil is $E_L = I \times X_L = 5 \times 4 = 20$ volts.

You might wonder about the 60 Hertz. We didn't use this, because we didn't have to. We had the reactance of the coil and capacitor so we could get the impedance directly. Often, in problems and in actual practice, you'll find you have more data than you need. You have to learn to take what information is needed and use it and ignore unneeded information.

SELF-TEST QUESTIONS

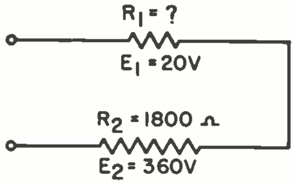
(48) If a 500-ft. roll of copper hookup wire has a resistance of 30 ohms, how much resistance will an 850-ft. roll of the same wire have?

(49) What ac voltage will be needed to force a current of .02 amps through an 8K-ohm resistor?

(50) What value of ac current will flow through a 10-henry coil with negligible resistance if the voltage supplied is 120-volt, 60 Hertz ac?

(51) Find the current sent through a .03-henry choke coil by an ac voltage of 188.4 volts at 1 kHz.

(52) In the circuit shown below, find the resistance of R_1.



(53) A 10 mfd capacitor draws 300 ma of current at a frequency of .4 kHz. What is the voltage drop across the capacitor?

(54) What turns ratio should we have for a transformer that we wish to use to match a source impedance of 490 ohms to a load of 10 ohms?

(55) What is the total inductance of two coils connected in series if the inductance of one is .2 henrys and the other is .8 henrys and their mutual inductance is zero?

(56) What is the impedance of a series ac circuit having an inductive reactance of 14 ohms, a resistance of 6 ohms, and a capacitive reactance of 6 ohms?

(57) What is the resonant frequency of a series circuit containing a 500 picofarad capacitor, a 150 microhenry choke and a 10-ohm resistor?

(58) What is the impedance of an ac circuit containing a 3-ohm resistor in series with an inductive reactance of 7 ohms?

(59) If three capacitors of 1, 3, and 5 microfarads are connected in parallel, what will the total capacitance be?

(60) If we assume that a coil has a negligible resistance and that 215 ma of current is forced through it

by a supply voltage of 110 volts at 25 Hertz what is the inductance of the coil?

(61) If we supply 240 volts at 60 Hertz to a capacitor and obtain a current of 452 ma, what is the capacitance?

(62) If a circuit containing a 175-ohm resistor is connected in series with a 5-microfarad capacitor across a source of 150 volts at 120 Hertz, what current will flow in the circuit?

(63) If a series circuit contains a capacitive reactance of 10 ohms, an inductive reactance of 25 ohms, and a resistance of 15 ohms, what will the phase angle be?

(64) What is the capacitive reactance of a capacitor at a frequency of 1200 kHz if its reactance is 300 ohms at 680 kHz?

(65) If a series circuit has a resistance of 4 ohms, an inductive reactance of 4 ohms, and a capacitive reactance of 1 ohm, and it is supplied with an ac voltage of 50 volts, what will the voltage drop across the inductance be?

Answers to Self-Test Questions

(1) The radical sign.

(2) 25 ohms.

$$Z = \sqrt{R^2 + X^2}$$

$$= \sqrt{(15)^2 + (20)^2}$$

$$= \sqrt{225 + 400}$$

$$= \sqrt{625}$$

$$\begin{array}{rl} & \ \ 2\ \ 5 \\ = & \sqrt{\ 6,25} \\ & -4 \\ 45 & \overline{)2\ 25} \\ & -2\ 25 \end{array}$$

$Z = 25$ ohms

(3) Approximately 1.414.

$$\begin{array}{rl} & \ \ 1.\ 4\ \ 1\ \ 4 \\ & \sqrt{2.00,00,00} \\ & -1 \\ 24 & \overline{)1\ 00} \\ & -96 \\ 281 & \overline{)4\ 00} \\ & -2\ 81 \\ 2824 & \overline{)1\ 19\ 00} \\ & -1\ 12\ 96 \end{array}$$

(4) $\frac{1}{5}\ \sqrt{\frac{25}{625}} = \frac{1}{25} = \frac{\sqrt{1}}{\sqrt{25}} = \frac{1}{5}$

(5) 111. This is the same as saying, "What is the square root of 12,321."?

$$\begin{array}{rl} & \ \ 1\ \ 1\ \ 1 \\ & \sqrt{1,23,21} \\ & -1 \\ 21 & \overline{)23} \\ & -21 \\ 221 & \overline{)2\ 21} \\ & -2\ 21 \end{array}$$

(6) 21.2.

$$\begin{array}{rl} & \ \ 2\ \ 1.\ 2 \\ & \sqrt{4,49.44} \\ & -4 \\ 41 & \overline{)49} \\ & -41 \\ 422 & \overline{)8\ 44} \\ & -8\ 44 \end{array}$$

(7) 50 ohms.

$$Z = \sqrt{R^2 + X^2}$$

$$= \sqrt{(40)^2 + (30)^2}$$

$$= \sqrt{1600 + 900}$$

$$\begin{array}{rl} & \ \ 5\ \ 0 \\ = & \sqrt{25,00} \\ & -25 \end{array}$$

$Z = 50$ ohms

(8) 663.

$$\begin{array}{rl} & \ \ 6\ \ 6\ \ 3 \\ & \sqrt{43,95,69} \\ & -36 \\ 126 & \overline{)7\ 95} \\ & -7\ 56 \\ 1323 & \overline{)39\ 69} \\ & -39\ 69 \end{array}$$

(9) .021.

$$\begin{array}{r|l} & .\;0\;\;2\;\;1 \\ & \sqrt{.00,04,41} \\ & -00 \\ 2 & \quad 04 \\ & \;-04 \\ 41 & \quad\;\; 41 \\ & \quad -41 \end{array}$$

(10) 5.01.

$$\begin{array}{r|l} & 5.\;0\;\;1 \\ & \sqrt{25.10,01} \\ & -25 \\ 1001 & \quad 10,01 \\ & \;-10\,01 \end{array}$$

(11) A ratio is a comparison of two numbers or similar quantities. For example, the efficiency of a motor is expressed as the ratio of output power to input power. A proportion is a comparison of two ratios. To be more precise, a proportion is a mathematical statement that two ratios are equal.

(12) $$\text{Efficiency} = \frac{\text{Output power}}{\text{Input power}}$$

$$= \frac{2 \text{ horsepower}}{1.75 \text{ kW}}$$

(1 horsepower equals approximately 750 watts.)

$$= \frac{2 \times 750}{1.75 \times 1000}$$

$$= \frac{1500}{1750}$$

$$= \frac{6}{7}$$

$$= .857 \text{ or } 85.7\%$$

(13) $$\frac{6\text{V}}{18\text{V}} = \frac{1}{3} = 1{:}3$$

(14) $$\frac{250 \text{ mV}}{1\text{V}} = \frac{250 \text{ mV}}{1000 \text{ mV}} = \frac{1}{4} = 1{:}4$$

(15) $$\text{Efficiency} = \frac{\text{Output power}}{\text{Input power}}$$

$$= \frac{3\text{hp}}{2.5\text{kW}}$$

(1 horsepower equals approximately 750 watts.)

$$= \frac{3 \times 750}{2.5 \times 1000}$$

$$= \frac{2250}{2500}$$

$$= \frac{9}{10}$$

$$= .9 = 90\% \text{ efficiency}$$

(16) $$\frac{A_1}{A_2} = \frac{B_1}{B_2}$$

$$\frac{15}{6} = \frac{90}{B_2}$$

$$15B_2 = 540$$

$$B_2 = 36$$

(17) $$\frac{A_1}{A_2} = \frac{B_2}{B_1}$$

$$\frac{A_1}{4} = \frac{150}{100}$$

$$100A_1 = 600$$
$$A_1 = 6$$

(18) The battery voltage is equal to the sum of the voltage drops across the two resistors. The voltage across R_1 is 10 volts. Therefore, we can find the voltage across R_2 using direct proportion:

$$\frac{E_1}{E_2} = \frac{R_1}{R_2}$$

$$\frac{10}{E_2} = \frac{1200}{240}$$

$$1200E_2 = 2400$$
$$E_2 = 2 \text{ volts}$$

The applied battery voltage is the sum of $E_2 + E_1$ or $2V + 10V = 12V$.

(19) Since current is inversely proportional to resistance, our equation is:

$$\frac{I_1}{I_2} = \frac{R_2}{R_1}$$

$$\frac{2}{2.2} = \frac{R_2}{66}$$

$$2.2R_2 = 132$$
$$R_2 = 60 \text{ ohms}$$

(20) To add two or more numbers with like signs, find the sum of the numbers as you would in ordinary arithmetic and place the sign of the numbers added in front of this sum.

(21) The sum of two signed numbers with unlike signs is equal to the difference between the two numbers, preceded by the sign of the larger number.

(22) To subtract signed numbers change the sign of the subtrahend and then add the two numbers according to the rules for adding signed numbers.

(23) −3

(24) (a) −23 (b) +9 (c) +26 (d) −22

(25) (a) −9 (b) +17 (c) −70 (d) −46

(26) The product of two numbers with like signs is always positive. The product of two numbers with unlike signs is always negative.

(27) If the numbers have like signs, the quotient is always positive. If the numbers have unlike signs, the quotient is always negative.

(28) (a) +42 (b) −18 (c) −187 (d) +36

(29) (a) −4 (b) +24 (c) −3 (d) +43

(30) A positive number.

(31) (a) −8 (b) +24 (c) −27 (d) 0

(32) (a) +138 (b) −22 (c) −59 (d) −12

(33) (a) +126 (b) −120 (c) −56 (d) +120

(34) (a) +43 (b) −11 (c) −.25 (d) −16

(35) (a) $(-2)^4 = (-2) \times (-2) \times (-2) \times (-2) = +16$

(b) $(+2)^4 = (+2) \times (+2) \times (+2) \times (+2) = +16$

(c) $(-3)^3 = (-3) \times (-3) \times (-3) = -27$

(d) $(+3)^3 = (+3) \times (+3) \times (+3) = +27$

(36) (a) 3.247
(b) 762,500
(c) .0023
(d) .0967
(e) 2,300,000
(f) .9327
(g) 8200
(h) .00032
(i) 75.6

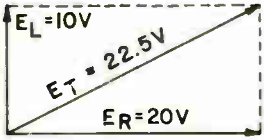
(37) (a) 2.68
(b) -2.25
(c) 1.97×10
(d) -7.57×10^{-1}
(e) 2.67×10^{-4}
(f) 5.57×10^{-2}
(g) 3.14×10^{4}
(h) 6.85×10^{-1}
(i) 7.78×10^{2}
(j) -8.15×10^{-1}

(38) A vector is a straight line of definite length and direction which shows the magnitude and direction or time of a quantity.

(39) See Fig. 27B.

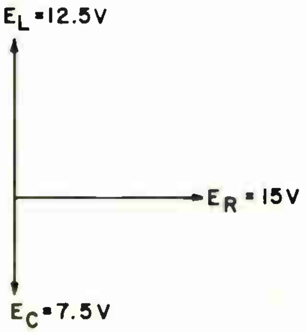
(40)

(41) Approximately 22.5 volts.

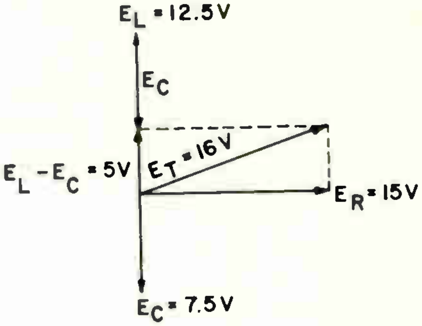


(42) See Fig. 34C.

(43)



(44) Approximately 16 volts.



(45) The Pythagorean Theorem states that the square of the hypotenuse of any right triangle is equal to the sum of the squares of the other two sides.

(46) Any triangle which contains one angle that is equal to 90°.

(47) Impedance.

(48) 51 ohms.

L_L = Length of long wire
L_S = Length of short wire
R_L = Resistance of long wire
R_S = Resistance of short wire.

Now, since the resistance of a wire is directly proportional to its length, we can establish a proportion.

$$\frac{L_L}{L_S} = \frac{R_L}{R_S}$$

$$\frac{\overset{17}{\cancel{850}}}{\underset{10}{\cancel{500}}} = \frac{R_L}{30}$$

$$10R_L = 510$$
$$R_L = 51 \text{ ohms}$$

(49) 160 volts. First convert 8K-ohms to ohms.

8K-ohms = 8000 ohms

Then use Ohm's Law to find the voltage.

$E = IR$
$E = .02 \times 8000$
$E = 160$ volts

(50) .0318 amps. Use Ohms's Law for ac circuits.

$$I = \frac{E}{Z}$$

The only impedance in the circuit is the X_L of the coil. Therefore, $I = E/X_L$, so we must first find X_L.

$X_L = 2\pi fL$
$f = 60$ Hertz
$L = 10$ henrys
$X_L = 6.28 \times 60 \times 10$
$X_L = 3768$ ohms

Now,

$$I = \frac{E}{X_L}$$

$$I = \frac{120}{3768}$$

$I = .0318$ amps

(51) 1 amp.
$X_L = 2\pi fL$
$f = 1$ kHz or 1000 Hertz
$L = .03$ henry
$X_L = 6.28 \times 1000 \times .03$
$X_L = 188.4$ ohms

$$I = \frac{E}{X_L}$$

$$I = \frac{188.4}{188.4}$$

$I = 1$ amp.

(52) $R_1 = 100$ ohms.

$$\frac{R_1}{R_2} = \frac{E_1}{E_2}$$

$$\frac{R_1}{1800} = \frac{\overset{1}{\cancel{20}}}{\underset{18}{\cancel{360}}}$$

$18R_1 = 1800$
$R_1 = 100$ ohms

(53) 12 volts. First find X_C.

$$X_C = \frac{.159}{fC}$$

$f = .4$ kHz or 400 Hertz
$C = 10$ mfd or .00001 farad

$$X_C = \frac{.159}{400(.00001)}$$

$$X_C = \frac{.159}{.004}$$

$X_C = 39.75$ ohms or approximately 40 ohms

$E = IX_C$
$I = 300$ ma or .3 amps
$E = .3 \times 40$
$E = 12$ volts

(54) 7 to 1.

$$\frac{N_1}{N_2} = \sqrt{\frac{Z_1}{Z_2}}$$

$$\frac{N_1}{N_2} = \sqrt{\frac{490}{10}}$$

$$\frac{N_1}{N_2} = \sqrt{49}$$

$$\frac{N_1}{N_2} = 7$$

Therefore, the turns ratio is 7 to 1.

(55) 1 henry.

$$L_T = L_1 + L_2 \pm 2M$$
$$L_T = .2 + .8$$
$$L_T = 1 \text{ henry}$$

(56) 10 ohms.

$$Z = \sqrt{R^2 + [X_L + (-X_C)]^2}$$

$$Z = \sqrt{6^2 + [14 + (-6)]^2}$$

$$Z = \sqrt{6^2 + 8^2}$$

$$Z = \sqrt{36 + 64}$$

$$Z = \sqrt{100}$$

$$Z = 10 \text{ ohms}$$

(57) Approximately 580 kHz.

$$f = \frac{.159}{\sqrt{LC}}$$

$$f = \frac{.159}{\sqrt{1.5 \times 10^{-4} \times 5 \times 10^{-10}}}$$

$$f = \frac{.159}{\sqrt{7.5 \times 10^{-14}}}$$

$$f = \frac{.159}{2.74 \times 10^{-7}}$$

$$f = 5.8 \times 10^5$$

$$f = 580 \text{ kHz}$$

(58) 7.6 ohms.

$$Z = \sqrt{R^2 + X_L{}^2}$$

$$Z = \sqrt{3^2 + 7^2}$$

$$Z = \sqrt{9 + 49}$$

$$Z = \sqrt{58}$$

$$Z = 7.6 \text{ ohms}$$

(59) 9 microfarads.

$$C_T = C_1 + C_2 + C_3$$
$$C_T = 1 + 3 + 5$$
$$C_T = 9 \text{ mfd.}$$

(60) Approximately 3.3 henrys. First find the X_L of the coil.

$$X_L = \frac{E}{I} = \frac{110}{.215} = 512 \text{ ohms}$$

Now, since $X_L = 2\pi fL$
Then,

$$L = \frac{X_L}{2\pi f}$$

$$L = \frac{512}{6.28(25)}$$

$$L = \frac{512}{157}$$

$$L = 3.3 \text{ henrys.}$$

(61) 5 microfarads. First find the X_C of the capacitor.

$$X_C = \frac{E}{I} = \frac{240}{.452} = 531 \text{ ohms}$$

And since $X_C = \dfrac{.159}{fC}$

Then

$$C = \frac{.159}{fX_C}$$

$$C = \frac{.159}{60(531)}$$

$$C = \frac{.159}{31860}$$

$$C = .000005 = 5 \text{ mfd}$$

(62) .472 amps. $I = E/Z$, so we must first find Z. But to find Z we must find X_C.

$$Z = \sqrt{R^2 + X_C{}^2}$$

$$X_C = \frac{.159}{fC}$$

$$X_C = \frac{.159}{120(.000005)}$$

$$X_C = \frac{.159}{.0006}$$

$X_C = 265\Omega$. Now find Z.

$$Z = \sqrt{R^2 + X_C{}^2}$$

$$Z = \sqrt{175^2 + 265^2}$$

$$Z = \sqrt{30625 + 70225}$$

$$Z = \sqrt{100850}$$

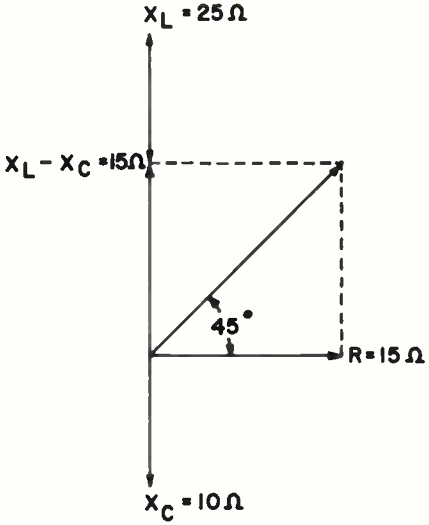
$Z = 318$ ohms. Now find I.

$$I = \frac{E}{Z}$$

$$I = \frac{150}{318}$$

$I = .472$ amps.

(63) 45° inductive.



(64) 170 ohms. There are two ways to work this problem. We will consider both ways. The easier method is to set up and solve a proportion. We know that X_C is inversely proportional to frequency. Therefore,

$$\frac{X_{C_1}}{X_{C_2}} = \frac{f_2}{f_1}$$

$$\frac{X_{C_1}}{300} = \frac{680}{1200}$$

$$1200\, X_{C_1} = 204000$$

$$X_{C_1} = \frac{204000}{1200} = 170 \text{ ohms.}$$

The second method is to find the capacitance of X_C and frequency given. Then find X_C of that capacitance at the new frequency.
That is,

$$C = \frac{.159}{fX_C} = \frac{.159}{680{,}000(300)}$$

$$= \frac{.159}{204{,}000{,}000}$$

C = 780 picofarads. Now find the reactance of this capacitance at the new frequency.

$$X_C = \frac{.159}{1{,}200{,}000(.000000000780)}$$

$$X_C = \frac{.159}{.000936}$$

X_C equals approximately 170 ohms. The answer does not work out exactly because we rounded off 2π and the value of C. By working both methods, it becomes obvious that the first method is not only easier, it is also more accurate.

(65) 40 volts. First find the impedance of the circuit.

$$Z = \sqrt{R^2 + [X_L + (-X_C)]^2}$$

$$Z = \sqrt{4^2 + [4 + (-1)]^2}$$

$$Z = \sqrt{16 + 9}$$

$$Z = \sqrt{25}$$

$$Z = 5 \text{ ohms.}$$

Now, find the current in the circuit.

$$I = \frac{E}{Z}$$

$$I = \frac{50}{5}$$

$$I = 10 \text{ amperes.}$$

Now, find the voltage across the coil (E_L).

$$E_L = I(X_L)$$
$$E_L = 10(4)$$
$$E_L = 40 \text{ volts.}$$

Lesson Questions

Be sure to number your Answer Sheet X109.

Place your Student Number on every Answer Sheet.

Most students want to know their grades as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of lessons before new ones can reach you.

1. Find the square root of:
   (a) 576 (b) 4489 (c)16384

2. Find the square root of:
   (a) 41616 (b) 73652 (c) .0625

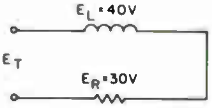
3. Find the value of X in each of the following:
   (a) 4 : 5 :: X : 20 (b) 47 : 329 :: 7 : X

4. Find the value of X in each of the following:
   (a) $\frac{62}{124} = \frac{3}{X}$ (b) $\frac{X}{72} = \frac{1}{12}$

5. Solve the following:
   (a) $(-47) \times (51)$
   (b) $(-23) \times (-17)$
   (c) $(37) \times (-62)$
   (d) $(-11) \times (-7) \times (-6)$

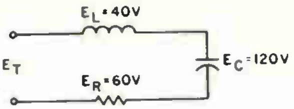
6. Solve the following:
   (a) $72 \div (-8)$
   (b) $(-144) \div (-12)$
   (c) $\frac{(-64)(-7)}{(-8)}$
   (d) $\frac{(-48)(-4)}{(12)}$

7. Find the value of E_T in the circuit at the right by means of a vector diagram. (Show your diagram.)



(OVER)

8. Find the value of E_T in the circuit at the right by means of a vector diagram. (Show your work.)



9. What is the total impedance of a circuit that has an inductive reactance of 124 ohms in series with a 95 ohm resistance?

10. Find the current in a series circuit made up of a coil with an inductance of 325 millihenrys, a capacitor of 4 microfarads, and a resistor of 120 ohms if the source voltage is 120 volts at 100 Hertz.

$\overset{6}{20\overline{)120}}$

$1'' = 40v$

$E_L = 1''$

THE VALUE OF KNOWLEDGE

Knowledge comes in mighty handy in the practical affairs of everyday life. For instance, it increases the value of your daily work and thereby increases your earning power. It brings you the respect of others. It enables you to understand the complex events of modern life, so you can get along better with other people. Thus, by bringing skill and power and understanding, knowledge gives you one essential requirement for true happiness.

But what knowledge should *you* look for? The first choice naturally goes to knowledge in the field of your greatest interest – electronics. Become just a little better informed than those you will work with, and your success will be assured.

It pays to know – but it pays even more to know how to use what you know. You must be able to make *your* knowledge of value to others, and to the rest of the world, in order to get cash for knowledge.

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STUDY SCHEDULE

☐ 1. **Introduction** .... **Pages 1 - 2**

This section explains why you need some new mathematical tools as the circuits you study become more complex.

☐ 2. **Basic Algebra** .... **Pages 3 - 21**

You learn how to apply the rules of arithmetic to combinations of letters in this section.

☐ 3. **Equations** .... **Pages 22 - 34**

Here you work with equations, and then learn how to solve them step-by-step. This section also covers the numerical representation of vectors.

☐ 4. **The J Operator** .... **Pages 35 - 44**

The term j is defined and you learn how it can be used as an operator in ac circuits.

☐ 5. **Using the J Operator in Circuit Operations** .... **Pages 45 - 60**

You get practice applying the information you have learned in this lesson to problems and circuit calculations.

☐ 6. **Answers to Self-Test Questions** .... **Pages 61 - 68**

☐ 7. **Answer Lesson Questions.**

☐ 8. **Start Studying the Next Lesson.**

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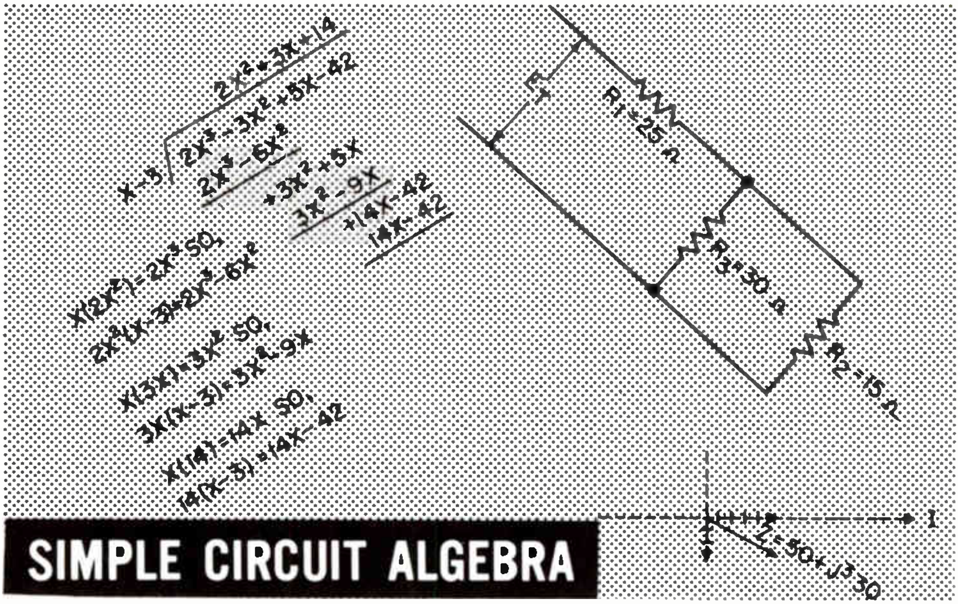


SIMPLE CIRCUIT ALGEBRA

In many ways the study of tube and transistor circuits is just an extension of your study of ac and dc circuits. The tuning circuits, coupling circuits, filter circuits, and voltage dividers that are used with tubes and transistors are simply special designs of circuits that you are already familiar with to a certain extent. In these circuits, coils and capacitors and resistors of various values are assembled in different series and parallel combinations to give special effects. Either ac, dc, or both may be applied to these circuits depending on their function and use.

For the most part, the basic arithmetic and operations with signed numbers and vectors that you studied for use with ac and dc circuit calculations can be applied in the calculations for tube and transistor circuits. However, as the equipment and circuits that you study become more involved, it will become increasingly difficult to keep up with their operation and maintenance if you rely only on the mathematical processes that you have already learned. You will need many new shortcuts and some new mathematical tools to keep your studies and work in electronics simple and straightforward.

In your previous lessons, you saw how important vectors are in analyses and calculations dealing with ac circuits. As you continue with your studies, these simple vectors will become even more important. However, the simple measurement solutions that you have been using to solve vector problems will become very awkward to use as the circuits become more complex. In addition to requiring careful construction and measurement, they require a lot of space and can become very involved, especially in parallel circuits. Although we can overcome these problems to some extent by using the Pythagorean Theorem, it also has its limits.

However, there is a handy method for working with ac circuit vectors so they can be solved mathematically. It involves using a special tool known as the "j" operator. This simple operator allows us to easily add, subtract, multiply, and divide vectors, regardless of their complexity. No course in electronics can really be considered complete without at least a working knowledge of this method of determining the solutions to circuit problems.

In order to use the j operator successfully, you should have at least a basic understanding of the essentials of another mathematical process known as algebra. As many of you already know, algebra is simply a form of mathematics that simplifies complex operations in arithmetic by using letters. Through these letter solutions of practical problems, we are able to speed up and simplify operations that would take a long time and involve a lot of tedious work if we used numbers alone. Thus, time spent learning the fundamentals of algebra will be worthwhile.

Therefore, in this lesson on circuit calculations, you will learn to use and apply the fundamentals of algebra and the j operator in electronic circuit calculations. If you have never studied these subjects, you may be a little uneasy about tackling them. However, you have already seen that math makes a lot more sense and becomes much easier when you have a practical use for it, such as your work in electronics.

As you study this lesson, remember these subjects are like all the others. All you have to do is learn a few rules and get some practice using them. Once you have done this, you have accomplished your goal of learning new processes that will help make your work much easier and more efficient. If you have already studied these subjects, you will find that this lesson will give you a good review and some valuable pointers on circuit applications.

Basic Algebra

Anyone who can add and subtract, multiply and divide, and perform the other operations of basic arithmetic should find algebra easy to understand. The only difference between algebra and arithmetic is that in algebra you work with letters as well as with numbers. Therefore, we can consider that algebra is simply arithmetic with letters. Consequently, all we have to do is get used to applying the rules of arithmetic to combinations of letters.

You are probably wondering just how we can use letters to compute with, because letters have no indicated values such as numbers have. We merely select letters and let them represent the values that we wish to work with. For example, you are already accustomed to working with formulas such as Ohm's Law which states that $E = I \times R$. Here we have simply used certain letters to indicate various quantities in our circuit and have used these letters in an equation that represents their relationship in an electrical circuit. This is algebra.

In ordinary arithmetic, the next step would be to substitute the actual number values in place of the letters and solve the problem. In algebra, we may also do this, but many times we will find that it is easier to work with the letters awhile before we substitute the numbers. In this section of the lesson, we will start at the very beginning and learn just what algebra is all about.

THE LANGUAGE OF LETTERS

In your earlier lessons you learned how to substitute numbers for letters in certain formulas. As you continue in your work in electronics, it will be handy to know more about the process of computing with both numbers and letters. You are already familiar with this sort of reasoning: "If I have one resistor and you give me another resistor, I will have two resistors." Or, "If you give me four capacitors and then someone else gives me five more capacitors, I will have nine capacitors." This is simply addition as applied to physical things.

Addition, as you know, can only be performed with like things. We can add resistors to resistors, or capacitors to capacitors, but we can never add a number of resistors to a number of capacitors and get a sensible answer. Thus, the result of any addition is the sum of the number of things added followed by their name. We know that it is possible to represent various quantities by letters. For example, suppose that we receive three orders of parts as follows:

(1) 5 choke coils, 7 resistors, 4 capacitors.

(2) 3 choke coils, 2 resistors, 3 capacitors.

(3) 7 choke coils, 4 resistors, 5 capacitors.

If we want to know the total number of parts received in these orders we can simply add the number of like parts in each order together to give us a total of 15 choke coils, 13 resistors, and 12 capacitors.

However, in doing this we must be very careful to keep the numbers associated with the coils separated from the numbers associated with the resistors, and resistors separated from the capacitors, etc. Otherwise, there is a possibility that we might get the numbers confused and start adding the coils to one of the other parts. To keep them separated, we can list them carefully in separate columns and write down the names of the parts as we just did. While this will work very well, you can easily see that it would require a lot of tedious writing if we needed to add a number of different things.

A much simpler way would be to choose abbreviations for the parts. For example, we could decide to let the letter "c" stand for the coils, the letter "r" stand for the resistors, and then let another letter such as "a" stand for the capacitors to be sure that the coils and capacitors are kept separate, since they both begin with "c." Now our additions and notations would look something like this (where c = choke coils, r = resistors, a = capacitors):

(1) 5c, 7r, 4a

(2) 3c, 2r, 3a

(3) 7c, 4r, 5a

15c,13r,12a

By doing this we could save ourselves a lot of work and still perform the addition in such a way that it would make sense and eliminate the chance of getting the different parts confused with each other.

In this way, it is possible to represent any number of different things or quantities with letters. Once we have chosen letters to indicate quantities, we can add or subtract them, or multiply and divide them by simply performing the operations with the letters instead of using the quantities themselves.

For example, let's say that we choose the letter "a" to represent a quantity. This means that the letter "a" written by itself will always mean "1 a," the term "2a" will mean "2 a's," "3a" will mean "3 a's," etc. Thus, a term such as "5a" means that the quantity represented by the letter "a" is to be multiplied by 5. When we get ready to substitute and actually find the value or the meaning of the term "5a," we will need to know what the letter "a" stands for. In the meantime, we can go along and work with the term itself without worrying about what it means.

Another example of a term that we are likely to meet is one such as "6ab." This simply means that a quantity represented by "a" is to be multiplied by a quantity represented by "b." Then the product of quantity "a" times quantity "b" is to be multiplied by 6. Thus, 6ab means "6" times "a" times "b" or 6 × a × b. In working with algebra we usually do not use the symbol × as a "times" sign because it can be confused with the letter "x" which can be used to represent a quantity. Sometimes dots are used between letters to indicate multiplication, as "6 · a · b," but generally the letters are simply written close together without any sign between them.

Before we go on to learn the rules of using letters, there are some special names given letter combinations that we should be familiar with. A letter by itself is called a "term." Thus "a" is a term, "b" is a term, "x" is a term, etc. The indicated product of a group of letters such as "6ab" is also called a term. In this term, the 6, the a, and the b, are all factors of the indicated product, just as 6 and 8 are factors of 48.

We may have "like" terms or "unlike" terms in algebra. For example, 6ab, 3ab, and 5ab are all like terms because their letter factors are all the same. Terms such as 6xy, 10ax, 7ab, are unlike terms because their letter factors are not all the same.

The number tells you how many times the letter term is to be multiplied. It is called the "numerical coefficient" of the term or, more simply, just the "coefficient." Thus, a term may be a single letter, or it may consist of an indicated product between two or more letters, or between one or more letters and a numerical coefficient. Remember, a term may consist of one or more letters and numbers, but if more than one letter appears, it is a term only if multiplication is indicated. The expression, "a + b", is two separate terms because addition is indicated between the two letters. Likewise, an expression such as 6ab – cd is also made up of two terms.

An algebraic expression made up of one term such as "7xyz" is called a "monomial" term. An expression made up of two or more terms, such as 6ir + 7abc, or 8yx + 7cd – ab is called a "polynomial." If a polynomial has only two terms, it is usually called a "binomial" and one with three terms is often called a "trinomial." Thus, ab + ac is a binomial, and ab + ac + ad would be called a trinomial. We have no special names for polynomials that consist of more than three terms. For example, an expression such as xy + ab – ac – yb would simply be called a four-term polynomial.

Now, with the names given to these various expressions firmly in mind, let's see how to perform simple arithmetic with letters.

Addition of Letters. The rules for performing arithmetic with letters are the same as those with numbers. We can add like terms to each other, but we cannot add unlike terms. The rules for working with signed numbers also apply to working with letters. Likewise, the rules of order for performing a series of operations apply to letter arithmetic, or algebra, just as they do to numbers.

A term consisting of a letter with a coefficient, such as 5a, means that "a" is to be taken five times, or a+a+a+a+a. A term such as 6a means a+a+a+a+a+a. Therefore, to add 5a and 6a together really means (a+a+a+a+a) + (a+a+a+a+a+a), or a total of 11 a's which we would write as 11a. Accordingly, we can say that 5a + 6a = 11a. We can perform the indicated addition because the letter factors are the same and we can add like things together. Notice that in adding these like terms, we simply added their numerical coefficients (6 and 5) and used this sum as the new coefficient for the common letter. Thus, *the sum of like terms is the sum of the coefficients of the terms followed by the common letters.* For example,

$$6ab + 3ab = 9ab$$

$$4abc + 3abc + 5abc = 12abc$$

$$xy + 3xy + 8xy = 12xy$$

When working with unlike terms, however, we can only indicate the addition to be performed. Thus, a + b can only be written as a + b. Likewise, 6a + 5b must remain as 6a + 5b as far as the addition is concerned. Thus, addition of unlike terms always results in a polynomial term. Consequently, when we have addition indicated in a problem such as

$$6a + 7b + 9ab + 4a + 3b + b,$$

we would proceed as follows.

First, we would arrange the terms so that all the like terms were grouped together. Thus, we would have $6a + 4a + 7b + 3b + b + 9ab$. Now, adding the like terms gives us

$$6a + 4a = 10a,$$

and

$$7b + 3b + b = 11b.$$

Since we now have $10a + 11b + 9ab$, which are all unlike terms and cannot be added any further, our answer to our problem of

$$6a + 7b + 9ab + 4a + 3b + b$$

is simply

$$10a + 11b + 9ab.$$

Thus, to add a group of terms in algebra arrange the like terms so that they are together, then add all the like terms by adding their coefficients and then use these sums in an indicated addition of the unlike terms. The process of rearranging and adding the like terms is often called "collecting" terms.

In working with letters, we will often run into terms with negative signs just as in working with numbers. We handle these signed algebraic terms like signed numbers. For example, to add two terms with like signs, we add the coefficients and use the common sign in front of the sum. Thus, $(-6ab) + (-4ab)$ would be equal to $-10ab$, just as $+3ab$ plus $+4ab$ would equal $+7ab$.

If we have to add terms with unlike signs, we simply find the difference between the coefficients and use the sign of the largest coefficient. Thus,

$$+5c + (-3c) = +2c$$

and

$$-7cd + 4cd = -3cd.$$

In a more complicated problem that consists of like and unlike terms as well as like and unlike signs, we would simplify the problem by collecting all like terms with like signs and then perform the addition. Thus, for a problem such as

$$4c + (-9d) + 6e + (-3e) + 12d + (-4x) + 2c + (-c) + 3d + 4e + (-3c) + (-3d),$$

we would first collect all our like terms and like signs as follows:

$$4c + 2c + (-c) + (-3c)$$

$$+ 12d + 3d + (-3d) + (-9d)$$

$$+ 6e + 4e + (-3e) + (-4x).$$

$$+ (-4x).$$

Then, combine like terms:

$$6c + (-4c)$$

$$+ 15d + (-12d)$$

$$+ 10e + (-3e) + (-4x).$$

$$+ (-4x).$$

Now,

$$6c + (-4c) = 2c$$

$$15d + (-12d) = 3d$$

$$10e + (-3e) = 7e$$

$$+ (-4x) = -4x$$

and our answer would be

$$2c + 3d + 7e + (-4x)$$

or simply $2c + 3d + 7e - 4x$.

We will also find terms like this to add:

$$(6ab-7xy) + (5ab-xy) + (-3ab+4xy).$$

Here we have to add three binomials but the terms in each binomial are alike, so we can add them quite easily like this:

$$\begin{array}{rrr} & 6ab & -\ 7xy \\ + & 5ab & -\ \ xy \\ & -3ab & +\ 4xy \\ \hline & 8ab & -\ 4xy \end{array}$$

Or, collecting terms like this:

$$6ab + 5ab + 4xy - 3ab - 7xy - xy$$

then:

$$11ab + 4xy - 3ab - 8xy$$

and:

$$11ab - 3ab + 4xy - 8xy = 8ab - 4xy.$$

Now suppose we had a problem like this:

$$(4x - 3y + 6c) + (-3x + 2y - 3d) + (2x - 7c + 2d).$$

Here we have three trinomials with terms that are not all alike. In a case like this we can set up our problem as follows:

$$\begin{array}{rrrrr} & 4x & -\ 3y & +\ 6c & \\ + & -\ 3x & +\ 2y & & -\ 3d \\ & 2x & & -\ 7c & +\ 2d \\ \hline & 3x & -\ \ y & -\ \ c & -\ \ d \end{array}$$

Since we cannot add unlike terms, this is as far as we can go with our answer. Notice that we could also have proceeded like this:

$$(4x - 3y + 6c) + (-3x + 2y - 3d) + (2x - 7c + 2d)$$

Collecting like terms and like signs:

$$4x + 2x - 3x + 2y - 3y + 6c - 7c + 2d - 3d$$

Then:

$$3x - y - c - d$$

which is the same answer we got before.

Now you should be able to add the following terms without any trouble:

(1) $3x - 2y + 4z + 2x + 8y - 2z + 12x + y + z =$

(2) $5ab - 6xy - 3ab + 12xy + 3ax - 5xb + ab - 3xy - 2xb =$

(3) $(12a + 6c - 3d) + (-20a + 8c - 5d) + (10a - 2c + d) =$

Answers:

(1) $17x + 7y + 3z$

(2) $3ab + 3xy + 3ax - 7xb$

(3) $2a + 12c - 7d$

Subtraction of Letters. When you

learned to subtract signed numbers, you found by experimenting with numbers of various signs that a simple rule would apply to all subtraction with signed numbers. This rule stated that: *To subtract signed numbers, change the sign of the number in the subtrahend (the number you are subtracting) and then proceed as in adding signed numbers.* Following this rule, + 7 minus – 6 would be handled this way:

$$\begin{array}{r} +7 \\ -\ (-6) \\ \hline \end{array} = \begin{array}{r} +7 \\ +6 \\ \hline +13 \end{array}$$

Thus, $+7-(-6)=13$.
To prove this, add the subtrahend, – 6, and the answer, + 13, which gives $-6+13=+7$, which is the minuend. Likewise, $-7-(-6)=$

$$\begin{array}{r} -7 \\ -\ (-6) \\ \hline \end{array} = \begin{array}{r} -7 \\ +6 \\ \hline -1 \end{array}$$

The proof is that $-1+(-6)=-7$.

Subtracting terms in algebra is just like subtracting signed numbers in arithmetic. Thus, if we want to subtract 6a from 8a we would have: + 8a minus + 6a, which is written $(+8a)-(+6a)$. Now, changing both signs in front of 6a, we get

$$(+8a)+(-6a).$$

Adding:

$$\begin{array}{r} +8a \\ -6a \\ \hline +2a \end{array}$$

To prove this, we add + 6a (the subtrahend) and + 2a which gives us the + 8a that we started with. As with addition in algebra, we can subtract only like terms. Thus, we can state a rule for subtraction in algebra which is: *To subtract in algebra, change the sign of the terms in the subtrahend and then add the coefficients of the like terms.*

This rule for subtraction in algebra holds true for either single terms or for polynomials. For example, to subtract $(2a-2b-3c)$ from $(3a-4b+5c)$ we would first change the sign of the subtrahend. $2a-2b-3c$ then becomes $-2a+2b+3c$. Now, we proceed to add:

$$(3a-4b+5c)+(-2a+2b+3c)$$

collecting terms

$$=3a-2a-4b+2b+5c+3c$$

$$=a-2b+8c.$$

Or, we could set it up like this:

$$\begin{array}{lr} & 3a-4b+5c \\ + & -2a+2b+3c \\ \hline & a-2b+8c \end{array}$$

In either case, the difference is equal to $a-2b+8c$, which is the correct answer. To prove it, add the difference of $a-2b+8c$ to the subtrahend $2a-2b-3c$ which, by collecting terms, gives the sum:

$$a+2a-2b-2b+8c-3c$$
$$=3a-4b+5c$$

Thus, the important thing to remember in subtracting letters is to change the sign of the subtrahend and then add.

Now that we have seen how to add and subtract with letters, let's prove that what

LETTERS	NUMBER SUBSTITUTES
(5a+3b)+(-2a-6b)	[5(115)+3(95)]+[-2(115)-6(95)]
=5a-2a+3b-6b	=(575+285)+(-230-570)
=3a-3b	= 860-800=60

Fig. 1. Substituting numbers in place of letters in addition.

we are doing with the letters is correct by substituting numbers in place of the letters. Suppose that we want to add 5a + 3b to − 2a − 6b. Collecting terms, this gives us:

$$5a - 2a + 3b - 6b = 3a - 3b.$$

Now, let's substitute some numbers in this same problem. For example, suppose that we have chosen the letter "a" to represent "115" and the letter "b" to represent "95." We would set up the problems side by side, one using the coefficients and letters, and the other using the number values as shown in Fig. 1.

In this way, we find that the term answer is 3a − 3b, while the answer we got by substituting numbers is 60. Therefore 3a − 3b must be equal to 60. To prove this substitute the letter values in our answer 3a − 3b. Doing this, we have:

$$3a - 3b$$

$$= 3(115) - 3(95)$$

$$= 345 - 285$$

$$= 60$$

Thus, if we substitute the numbers in place of the letters in the beginning, we get an answer of 60. If we wish to work with the letters as long as we can, we get an answer 3a − 3b. However, we find that this is also equal to 60 when we substitute at the end of the problem. Since we get an answer of 60 either way, our process of adding letters must be correct.

Now, let's check a problem in subtraction the same way. Again, let a = 115 and b = 95. This time the problem is to subtract 3a − 2b from 5a − 7b as shown in Fig. 2. As you can see, the answer with the letters is 2a − 5b and the answer with the number substitutes is −245. Now let's substitute in our letter answer to see if we also get −245 for our final solution. Doing this, we have:

LETTERS:	NUMBER SUBSTITUTES:
FROM 5a − 7b TAKE 3a − 2b	5(115) − 7(95) TAKE 3(115) − 2(95)
5a − 7b − (3a − 2b)	5(115) − 7(95) − [3(115) − 2(95)]
CHANGING SIGNS:	
= 5a − 7b + (−3a + 2b)	= 575 − 665 + [−3(115) + 2(95)]
= 5a − 7b − 3a + 2b	= 575 − 665 − 345 + 190
= 5a − 3a − 7b + 2b	= 575 − 345 − 665 + 190
= 2a − 5b	= 230 − 475 = −245

Fig. 2. Substituting numbers in place of letters in subtraction.

$$2a - 5b$$

$$= 2(115) - 5(95)$$

$$= 230 - 475$$

$$= -245$$

Consequently, our method of handling subtraction with letters must also be correct, since in either case we get -245 for the final solution.

Next, let's take a look at multiplying and dividing with letters.

Multiplication of Letters. Multiplication with letters such as 3 times "a" may be indicated simply as 3a, which means "a" taken three times, or $a + a + a$. Likewise, $2 \times b$ is written 2b, which means "b" taken two times, or $b + b$. In multiplying two letters together such as "a" X "b" we write "ab", which means "a" taken "b" times, or "b" taken "a" times. For multiplication of two terms with coefficients, such as 3a times 2b, we actually perform the multiplication of the coefficients and then indicate the letter multiplication. We can do this because $3a \times 2b$ really means

$$3 \times a \times 2 \times b$$

$$= 6 \times a \times b$$

$$= 6 \times ab$$

$$= 6ab$$

Following this method,

$$3a \times 4b \times 2c$$

would equal

$$3 \times 4 \times 2 \times a \times b \times c = 24abc.$$

Now suppose that we want to multiply two like terms such as $2a \times 3a$. This can be rewritten as

$$2 \times 3 \times a \times a$$

or

$$6 \times a \times a = 6aa.$$

However, in arithmetic when we wanted to multiply a number by itself such as 5×5, we found that we would simply say, 5^2. The small "2" indicated the 5 was to be raised to the second power (multiplied by itself) or squared, and we called the "2" an exponent. We can also use exponents in algebra to indicate that a letter is to be multiplied by itself. Thus, $2a \times 3a = 6aa$ or $6a^2$. A multiplication such as $a \times a \times a$ is aaa or a^3 (read "a cubed"), and $a \times a \times a \times a \times a$ is aaaaa or a^5 (read "a to the fifth").

Using exponents in this way saves time. For example, 4a times 3ab becomes $4 \times 3 \times a \times a \times b$ or $12a^2b$. Now, there is an interesting thing about exponents that we should know. When we write the letter "a" alone, we really mean "a" taken once or a^1. However, just as we never indicate a coefficient of one, we never indicate an exponent of one. We say that the one is understood. For right now though, let's use the exponent "1" for a moment in order to examine the exponents as we multiply.

When we multiply $a \times a$, we can say that we have $a^1 \times a^1$. We know that this is equal to aa or a^1a^1 or a^2. Now, notice that the exponent "2" in a^2 is the sum of the exponents in the indicated multiplication.

$$a^1a^1 = a^{1+1} = a^2$$

Likewise,

$$a \times a \times a$$

$$= a^1 \times a^1 \times a^1$$

$$= a^{1+1+1}$$

$$= a^3$$

Thus, we have a rule for exponents in multiplication which states that: *To find the product of two or more powers of the same base, add the exponents.* According to this rule, $a^2 \times a^3 = a^{2+3}$ or a^5. If we do it the long way, we find that $a^2 = a \times a$ and

$$a^3 = a \times a \times a.$$

Therefore, $(a \times a) \times (a \times a \times a)$ = a taken five times, which is:

$$a \times a \times a \times a \times a = a^5.$$

Therefore, the rule for adding exponents must be correct.

Accordingly, a multiplication such as $5ab \times 3a^2b$ must equal:

$$5 \times 3 \times a^{1+2} \times b^{1+1}$$

$$= 15 \times a^3 \times b^2$$

$$= 15a^3b^2.$$

Likewise,

$$(3a^2b^3c^4) \times (25ab^2c^3)$$

$$= 3 \times 25 \times a^{2+1} \times b^{3+2} \times c^{4+3}$$

$$= 75a^3b^5c^7$$

Can you multiply $6a^3b^4$ by $5a^2b^3c$? The answer is $30a^5b^7c$.

These few simple steps cover the process of multiplying one single term (monomial) by another. However, in algebra, we must not only consider multiplying one monomial by another monomial, but we must also consider multiplying one polynomial by a monomial, and a polynomial by another polynomial. In considering the multiplication of a polynomial by a monomial, let's go back to our work with numbers for a moment.

For example, consider a number problem such as: $7 \times (3 + 2 + 5)$. We can write this down and solve it in a number of different ways. We can do the addition separately first, which gives us $7 \times (3 + 2 + 5) = 7 \times 10 = 70$, or we can multiply each number by seven and then add. This would give:

$$(7 \times 3) + (7 \times 2) + (7 \times 5) = 21 + 14 + 35$$

which also equals 70. Since this is true with numbers, it must also be true with letters.

Let's multiply the polynomial

$$b + c + d$$

by the monomial a. We would set it up like this:

$$a \times (b + c + d)$$

$$= a(b + c + d)$$

$$= ab + ac + ad$$

Thus, we can say that the product of a monomial and a polynomial is the sum of the products of the monomial and each term of the polynomial. Accordingly,

$$a(b - c + d - e) = ab - ac + ad - ae.$$

Notice that, as with signed numbers,

multiplication of unlike signs in algebra always gives a negative product, while the product of two terms with like signs is always positive. Or,

$$-b(a-c+d-e)=-ab+cb-db+eb.$$

With this in mind, we are ready to do a multiplication problem such as $3a^2b(2a+3b-7c)$. This equals

$$(3a^2b \times 2a)+(3a^2b \times 3b)$$

$$+[(3a^2b)\times(-7c)]$$

$$=6a^3b+9a^2b^2-21a^2bc$$

Or, we can set up the problem a different way. Let's try it with this problem: $4I^2R(3IR+5I+6R)$. Now, multiplying each term of the polynomial by the monomial gives us:

$$4I^2R \times 3IR = 12I^3R^2$$

$$4I^2R \times 5I = 20I^3R$$

$$4I^2R \times 6R = 24I^2R^2$$

The sum of the products is $12I^3R^2+20I^3R+24I^2R^2$.

Multiplying one polynomial by a binomial or by another polynomial is much the same. For example, multiplying the polynomial $(a+b-c)$ by the binomial $(a-b)$, we can think of $(a-b)$ as being a single multiplier. Thus, multiplying $(a-b)$ by each of the terms in the polynomial, we would have $(a-b)a$, then $(a-b)b$, and then $(a-b)(-c)$. Putting them together, we have

$$(a-b)a+(a-b)b+(a-b)(-c).$$

Now, the partial products would be:

$$(a-b)a=a^2-ab$$

$$(a-b)b=ab-b^2$$

$$(a-b)(-c)=-ac+bc$$

Then, adding these products gives us $a^2-ab+ab-b^2-ac+bc$. Collecting terms, we get $a^2-b^2-ac+bc$ as the answer. Notice that the $-ab$ and the $+ab$ cancel each other out just as $+2+(-2)$ would do.

In this way, we can say that the product of

$$(a-b)(a+b-c)=a^2-b^2-ac+bc.$$

We can prove that the solution to this problem is correct by substituting any numbers we want in place of the letters. For example, let's have $a=5$, $b=3$, and $c=2$. If we do this and substitute these values for the letters we have:

$$(a-b)(a+b-c)=a^2-b^2-ac+bc.$$

Then,

$$(5-3)(5+3-2)=$$
$$5^2-3^2-(5\times 2)+(3\times 2)$$

and

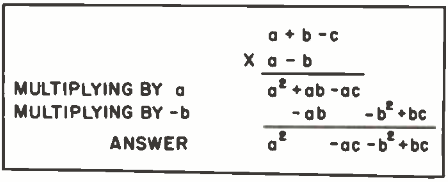
$$2\times 6=25-9-10+6$$

$$12=25-19+6=6+6=12$$

Since the problem works out so that 12 = 12, our multiplication of the letters must be correct.

We can also perform the multiplication by setting it down as in Fig. 3.

As you can see, we simply multiply all the terms in the polynomial by each term of the binomial. We do this by multi-



$$\begin{array}{lllll} & & a & +b & -c \\ & \times & a & -b & \\ \hline \text{MULTIPLYING BY } a & & a^2 & +ab & -ac \\ \text{MULTIPLYING BY } -b & & & -ab & \quad -b^2 + bc \\ \hline \text{ANSWER} & & a^2 & & -ac - b^2 + bc \end{array}$$

Fig. 3. Multiplying a polynomial by a binomial.

plying $a + b - c$ first by a, then by $-b$, and then adding the two partial products.

There are three polynomial products that we will find quite often in our work with algebra. They are:

(1) $(a + b)(a - b) = a^2 - b^2$

(2) $(a + b)(a + b)$ or $(a + b)^2$
$= a^2 + 2ab + b^2$

(3) $(a - b)(a - b)$ or $(a - b)^2$
$= a^2 - 2ab + b^2$

If we work each one of these out, we will find that the listed products are correct. Thus:

$$(1)\quad \begin{array}{lll} a & +b & \\ a & -b & \\ \hline a^2 & +ab & \\ & -ab & -b^2 \\ \hline a^2 & & -b^2 \end{array}$$

$$(2)\quad \begin{array}{lll} a & +b & \\ a & +b & \\ \hline a^2 & +ab & \\ & +ab & +b^2 \\ \hline a^2 & +2ab & +b^2 \end{array}$$

$$(3)\quad \begin{array}{lll} a & -b & \\ a & -b & \\ \hline a^2 & -ab & \\ & -ab & +b^2 \\ \hline a^2 & -2ab & +b^2 \end{array}$$

Sometimes these products are stated in words and used as rules:

1. The product of the sum of two terms $(a + b)$ *and the difference of the same two terms* $(a - b)$ *is equal to the square of the first term minus the square of the second term* $(a^2 - b^2)$.

This is a handy rule, because any time that we have to multiply the sum of two terms by the difference of the same two terms, we can just set down the answer without working it out. For example,

$$(4abc + 6xyz)(4abc - 6xyz)$$

must equal

$$(4abc)^2 - (6xyz)^2.$$

Likewise,

$$(4a^2b^3c^5 + 7x^2yz^3)(4a^2b^3c^5 - 7x^2yz^3)$$

must equal

$$(4a^2b^3c^5)^2 - (7x^2yz^3)^2.$$

The second example stated in words is:

2. The square of the sum of two terms $(a + b)^2$ *is equal to the square of the first term plus the square of the second term plus twice the product of the terms* $(a^2 + 2ab + b^2)$.

By using this rule, we automatically know that a binomial such as

$$(5xy + 3ab)^2$$

is equal to

$$(5xy)^2 + 2(15xyab) + (3ab)^2.$$

The third example covers the square of the difference of two terms:

3. The square of the difference of two terms $(a - b)^2$ is equal to the square of the first term plus the square of the second term minus twice the product of the terms.

Thus,

$$(16cd - 5x^2y)^2$$

is equal to

$$(16cd)^2 - 2(80cdx^2y) + (5x^2y)^2.$$

Since we often have to work with either the square of the sum or the square of the difference of two terms, we will use these rules quite a lot.

Can you find the products for the following problems?

(1) $(2x - 3)(3x + 7)$

(2) $(2x + 3)^2$

(3) $(5x^2 - 4y^2)(5x^2 + 4y^2)$

(4) $(6ab - c^2)^2$

Answers:

(1) $6x^2 + 5x - 21$

(2) $4x^2 + 12x + 9$

(3) $(5x^2)^2 - (4y^2)^2$ or $25x^4 - 16y^4$

(4) $(6ab)^2 - 2(6abc^2) + (c^2)^2$ or

$$36a^2b^2 - 12abc^2 + c^4.$$

Division with Letters. Division in algebra is just the reverse of multiplication. In division, we are given a product and one of the factors of the product and are asked to find the other factor. Remember, there are special names for the quantities in a division problem. The dividend is the product that is to be divided. The divisor is the factor by which the dividend is to be divided. The quotient is the result of the division, or the factor which we are to find. Thus: dividend ÷ divisor = quotient.

Also, multiplication is the proof of a division problem. Thus, $24 \div 6 = 4$ because $4 \times 6 = 24$; likewise,

$$24 \div 4 = 6$$

because $4 \times 6 = 24$. Accordingly, we can say that $ab \div a = b$ because $a \times b = ab$. The rules for the division of signed numbers also apply to the division of signed terms in algebra. Thus:

$+24 \div +6 = +4$ because $+4 \times (+6) = +24$

$-24 \div +6 = -4$ because $-4 \times (+6) = -24$

$+24 \div -6 = -4$ because $-4 \times (-6) = +24$

$-24 \div -6 = +4$ because $+4 \times (-6) = -24$

Accordingly, our rules for division of signed numbers and signed terms are:

If the dividend and the divisor have like signs, the quotient is positive.

If the dividend and the divisor have unlike signs, the quotient is negative.

Thus:

$ab \div b = a$ because $a \times b = ab$

$-ab \div b = -a$ because $-a \times b = -ab$

$ab \div -b = -a$ because $-a \times -b = ab$

$-ab \div -b = a$ because $a \times -b = -ab$

With this review and application of the general rules for division to letter problems, we are ready to look at the rules for handling exponents in division. You are already familiar with the fact that a^4 means

$$a \times a \times a \times a$$

and a^2 means $a \times a$. With this in mind, let's divide a^4 by a^2 and see what we get for an answer.

$$\begin{aligned} a^4 \div a^2 &= \frac{\cancel{a} \times \cancel{a} \times a \times a}{\cancel{a} \times \cancel{a}} \\ &= \frac{a \times a}{1} \\ &= a \times a \\ &= a^2 \end{aligned}$$

Likewise:

$$\begin{aligned} b^6 \div b^4 &= \frac{b^6}{b^4} \\ &= \frac{\cancel{b} \times \cancel{b} \times \cancel{b} \times \cancel{b} \times b \times b}{\cancel{b} \times \cancel{b} \times \cancel{b} \times \cancel{b}} \\ &= \frac{b \times b}{1} = b^2 \end{aligned}$$

And:

$$c^3 \div c^2 = \frac{c^3}{c^2} =$$

$$\frac{\cancel{c} \times \cancel{c} \times c}{\cancel{c} \times \cancel{c}} = \frac{c}{1} = c.$$

If you look at these examples closely, you will see that we could have obtained the same results by subtracting exponents.

$$a^4 \div a^2 = a^{4-(+2)} = a^2$$

$$b^6 \div b^4 = b^{6-(+4)} = b^2$$

$$c^3 \div c^2 = c^{3-(+2)} = c$$

Thus, just as we can multiply powers with the same base by adding exponents, we can divide two powers with the same base by subtracting exponents. Consequently,

$$a^6 b^3 \div a^5 b^2 = ab$$

and

$$x^3 y^2 \div xy = x^2 y$$

We can prove these answers by multiplying the quotients by the divisors to see if we get the original dividends. Doing this, we would have

$$ab \times a^5 b^2 = a^{1+5} b^{1+2} = a^6 b^3$$

and

$$(xy)(x^2y) = x^{1+2}y^{1+1} = x^3y^2$$

As we start working with division, we will find a few new situations regarding exponents. We know that any number divided by itself is equal to one. Thus,

$$\frac{6}{6} = 1, \frac{a}{a} = 1, \frac{3}{3} = 1$$

Now, if we follow our rules for dividing by subtracting exponents, we can see that if

$$\frac{a^3}{a^3} = 1,$$

that

$$a^3 \div a^3 = a^{3-(+3)} = a^0$$

which must also equal one. Likewise,

$$\frac{a}{a} = 1$$

$$a \div a = a^{1-(+1)}$$

$$= a^0 = 1$$

and

$$\frac{a^6}{a^6} = 1$$

$$a^6 \div a^6 = a^{6-(+6)}$$

$$= a^0 = 1$$

Thus, we have a new situation brought on by division which gives us an exponent of zero, and any factor with a zero exponent must equal 1. Remember, a factor by itself, such as "x", is considered to have an exponent of one, or x^1, and is equal to itself; but, a factor with an exponent of zero, such as b^0, can only be equal to the number 1.

If we look further into this problem of dividing by subtracting exponents, we will find that we can not only have positive exponents, such as 1, 2, 5, etc., and zero exponents, but we can also have negative exponents. This would occur if we had a division problem, such as $a^2 \div a^5$. This would be written either as

$$\frac{a^2}{a^5} = \frac{\cancel{a} \times \cancel{a}}{\cancel{a} \times \cancel{a} \times a \times a \times a}$$

$$= \frac{1}{a \times a \times a}$$

$$= \frac{1}{a^3}$$

or it could be written as

$$a^2 \div a^5 = a^{2-(+5)} = a^{-3}$$

If our answer can be either $1/a^3$ or a^{-3}, then a^{-3} must equal $1/a^3$. Thus, we can say that any factor with a negative exponent is equal to one divided by the factor with the exponent positive. Accordingly, $x^{-5} = 1/x^5$ and $c^{-3} = 1/c^3$.

Once again, we can prove that the reasoning behind negative exponents is correct by multiplying. For example, $x^4 \div x^7 = x^{4-(+7)} = x^{-3}$ because $x^{-3} \times x^7 = x^{-3+7} = x^4$ or $(x^4/x^7) = (1/x^3)$ because

$$\frac{1}{x^3} \times x^7$$

$$= \frac{x^7}{x^3} = x^4$$

The problems of division in algebra can be broken down into three general considerations the same as multiplication. First, we have the division of one monomial by another. Second, we have the division of a polynomial by a monomial. Third, we have the division of a polynomial by another polynomial.

In our review of division in general and our studies of handling exponents in division, we have covered the problem of dividing one monomial by another monomial. There is only one more thing that we must learn and that is what to do with the coefficients of terms. For example, suppose we want to divide $-12a^3x^4y$ by $4a^2x^2y$. We can set this up as

$$-12a^3x^4y,$$

$$4a^2x^2y$$

and then break it up into

$$\left(\frac{-12}{4}\right)\left(\frac{a^3}{a^2}\right)\left(\frac{x^4}{x^2}\right)\left(\frac{y}{y}\right)$$

We can see that this will reduce to:

$$(-3)(a)(x^2)(1).$$

Now, putting the quotients together we have $-3ax^2 1$ or just $-3ax^2$, since any quantity times one equals itself.

By breaking up our division problems in this way and following the rules for division of signed numbers and exponents, we can see how division is accomplished. As a general rule, we will not need to do this, because the division of most monomials by another monomial can be worked out mentally. For example, see if you can follow these monomial divisions:

(1) $$\frac{-14a^2b^4c}{-7ab^2c^3} = \frac{2ab^2}{c^2}$$

(2) $$\frac{4x^3y^5}{8x^5y^2} = \frac{y^3}{2x^2}$$

(3) $$\frac{28a^2b^4c^3}{-7b^3c^3} = -4a^2b$$

(4) $$\frac{-16e^3i^2r^5}{-4e^2i^2r^3} = 4er^2$$

In order to divide a polynomial by a monomial, let's consider numbers for a moment. 16 ÷ 2 = 8 because 2 × 8 = 16. Thus, if $3(a + 4) = 3a + 12$, then $(3a + 12) \div 3$ must equal

$$\frac{3a + 12}{3} = a + 4.$$

Similarly, if

$$3x(2x + 3y) = 6x^2 + 9xy,$$

then

$$\frac{6x^2 + 9xy}{3x}$$

must equal

$$2x + 3y.$$

Thus, we have a very simple rule for dividing a polynomial by a monomial. It is: *Divide each term in the polynomial dividend by the divisor, and then collect the terms in the quotient with the proper signs.*

For example,

$$8a^2b^3c - 12a^3b^2c^2 + 4a^2b^2c$$

divided by $4a^2b^2c$ can be set up as follows:

$$\frac{8a^2b^3c - 12a^3b^2c^2 + 4a^2b^2c}{4a^2b^2c}$$

equals

$$\frac{8a^2b^3c}{4a^2b^2c} = 2b$$

and

$$\frac{-12a^3b^2c^2}{4a^2b^2c} = -3ac$$

and

$$\frac{4a^2b^2c}{4a^2b^2c} = 1$$

Now, collecting terms we have

$$2b - 3ac + 1$$

for our answer.

Another example:

$$-27x^3y^2z^5 + 3x^4y^2z^4 - 9x^4y^3z^5$$

divided by $-3x^3y^2z^4$ is equal to:

$$\frac{-27x^3y^2z^5}{-3x^3y^2z^4} = 9z$$

and

$$\frac{3x^4y^2z^4}{-3x^3y^2z^4} = -x$$

and

$$\frac{-9x^4y^3z^5}{-3x^3y^2z^4} = 3xyz$$

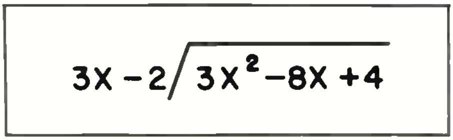


Fig. 4. Setting up a polynomial for division by another polynomial.

Now, collecting our quotient terms, we have our answer: 9z − x + 3xyz. Any polynomial can be divided by any monomial in this way.

In order to divide one polynomial by another polynomial, we must arrange the terms in a certain order before we actually divide. To do this, we simply make sure that all the terms in the dividend are arranged in the same order as those of the divisor. In doing this, we always place the term with the largest exponent first. Thus, in the problem $3x^2 + 4 - 8x$ divided by $3x - 2$, the divisor is correctly arranged, but the dividend isn't. Therefore, we must arrange it properly before we can proceed. Properly

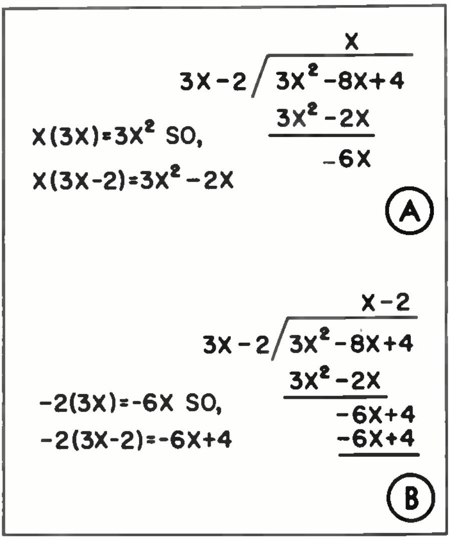


Fig. 5. (A) First steps in polynomial division. (B) Next step in polynomial division.

arranged, it should be written

$$3x^2 - 8x + 4.$$

Now that we have our terms arranged properly, we can set up our problem exactly as we did with long division of numbers shown in Fig. 4. Notice that we have the dividend set up under the division sign and the divisor at the left. Our process now is really just plain long division, as shown in Fig. 5A.

First, we see how many times the first term of our divisor will go into the first term of our polynomial dividend. For example, $3x$ will go into $3x^2$ x times, because $3x$ times x is equal to $3x^2$. Thus, x becomes our first term in our quotient as shown. Now we multiply our entire divisor, $3x - 2$, by x to give us our first trial product of $3x^2 - 2x$. We place this trial product under the proper terms of the divident and subtract.

Our remainder from this subtraction, plus the other term which we bring down from the dividend, can be considered to be a new dividend, as shown in Fig. 5B. Notice the sign of the first term. Signs are very important in algebra. Now, we see how many times the first term in our divisor will go into the first term in this new dividend. Since -2 times $3x$ equals $-6x$, we will try' the number 2 as the second term in our quotient. To do this, we place the -2 beside the x in our quotient, as shown, and then multiply our entire divisor by -2. As you can see, this gives us $-6x + 4$ as a trial product to subtract from the dividend. Since $-6x + 4$ from $-6x + 4$ leaves no remainder, our division is complete.

$$\begin{array}{r} 3X-2 \\ X-2 \\ \hline 3X^2-2X \\ -6X+4 \\ \hline 3X^2-8X+4 \end{array}$$

Fig. 6. Checking the answer in polynomial division.

$$\begin{array}{r|l} & 2X^2+3X+14 \\ \hline X-3 & 2X^3-3X^2+5X-42 \\ & \underline{2X^3-6X^2} \\ & +3X^2+5X \\ & \underline{3X^2-9X} \\ & +14X-42 \\ & \underline{14X-42} \end{array}$$

$X(2X^2) = 2X^3$ SO,
$2X^2(X-3) = 2X^3-6X^2$

$X(3X) = 3X^2$ SO,
$3X(X-3) = 3X^2-9X$

$X(14) = 14X$ SO,
$14(X-3) = 14X-42$

Fig. 7. Another problem in polynomial division.

In this way, we find that $3x^2 - 8x + 4$ divided by $3x - 2$ is equal to $x - 2$. To check our answer, we simply multiply the divisor by the quotient to see if we can get our dividend, as shown in Fig. 6. Since our answer checks, our problem is correct.

To make sure that we understand this, let's do another problem following the rules. Divide

$$5x - 42 + 2x^3 - 3x^2$$

by $x - 3$. Our first step is to rearrange the dividend in the proper order, which would give us

$$2x^3 - 3x^2 + 5x - 42$$

Now, we set up the problem for division, as shown in Fig. 7. Then, we see how

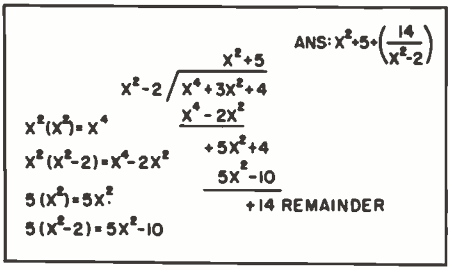


Fig. 8. Polynomial division with a remainder.

many times x will go into $2x^3$. Since $2x^2$ times x is equal to $2x^3$, we place $2x^2$ in our quotient and multiply the entire divisor by it. Since $2x^2(x - 3) = 2x^3 - 6x^2$, we use this as our first trial product and subtract it from the proper terms in the dividend.

Our remainder from this subtraction, plus the next term of our dividend, gives us a new dividend of $3x^2 + 5x$ to work with. x will go into $3x^2$, 3x times, so 3x becomes our next quotient term.

$$3x(x - 3) = 3x^2 - 9x,$$

which is the term we subtract from our new dividend. This makes our next dividend 14x – 42, as shown, and x – 3 will go into it exactly 14 times. Thus, our answer is $2x^2 + 3x + 14$. We can check this in the usual way, by multiplying the quotient and the divisor.

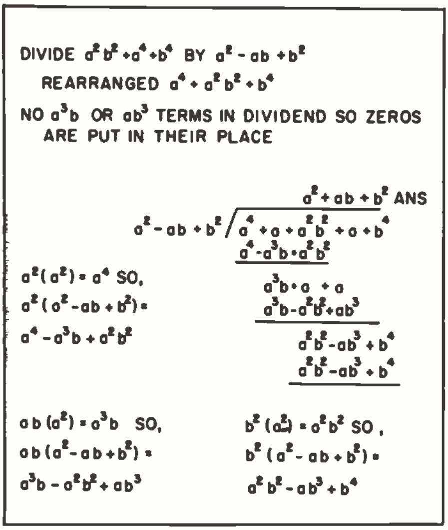


Fig. 9. A polynomial divided by a trinomial.

Some problems in division may not come out exactly even. It is possible to have a remainder in algebraic division, just as we do when working with numbers. An example of such a problem is shown in Fig. 8. Notice that we proceed to work it out just as we would any other problem until we get to a point where the first term of the divisor will not go into the dividend. When we come to this point, we simply stop and carry the remainder as a fraction in our answer, just as we do in ordinary arithmetic.

In Fig. 9, we have worked a problem where the divisor is a trinomial. As you can see, this is really no different from the problems we have been working, where the divisor is a binomial. You shouldn't have any trouble following this example.

SELF-TEST QUESTIONS

1. What is a monomial?
2. What is a polynomial?
3. Define binomial and trinomial.
4. What is an exponent?
5. What is the numerical coefficient of the term $6a^2b^3c$?
6. Add the following binomials: $3a^2b + 2b$; $a^2b - b$; and $-2a^2b + 4b$.
7. Add the following:

(a)

$$\begin{array}{r} 8x^2y + 9xy + 4y - 3 \\ -\,3x^2y + 2xy - 3y + 7 \\ 2x^2y + xy + 2y - 2 \\ \hline \end{array}$$

(b)
$$\begin{array}{rrr} 2a^4b^2 & -\ a^2b & \\ -\ 2a^4b^2 & -\ 3a^2b & +\ 3 \\ -\ 6a^4b^2 & +\ 4a^2b & -\ 5 \\ \hline \end{array}$$

8. Add the following: $4a^2b^2 - 2b$; $3ab^2 + 2a$; $a^2b^2 - 3a^2b + 3b + 3$.
9. Add the following:

(a)
$$\begin{array}{rrr} 4ab & +\ 2a & \\ -\ 2ab & -\ 4a & -\ 3 \\ ab & -\ a & \\ \hline \end{array}$$

(b)
$$\begin{array}{rrr} 3x^2y & +\ 2xy & -\ 2y \\ 5x^2y & +\ 3xy & +\ 4y \\ -\ 4x^2y & -\ xy & +\ y \\ \hline \end{array}$$

10. Add the following: $ab^2 + ab - 3a - b$; $a + b$; $3ab^2 - b$; $ab + 7a$; $ab + 3$.
11. Subtract $6a - 4b + 2c$ from $11a + b - 2c$.
12. Subtract $6a^2b + 3ab^2 - b^3$ from $a^3 - a^2b + 4ab^2$.
13. Subtract $a + b + c + d$ from $3a - 4b + c - 6d$.
14. Subtract $4a + 7b$ from $2a + 6b$.
15. Subtract $6a^3 - a^2b + ab^2 - b^3$ from $8a^3 + 3a^2b - ab^2 + b^3$.
16. Multiply $(a + 2b)$ times $(a - b)$.
17. Multiply $(a^2 + 2ab + b^2)(a + b)$.
18. Multiply $(2a + 3b)$ times $(2a - 3b)$.
19. Multiply $(a^2 - 2ab + b^2)$ by $(a + b)$.
20. Multiply $(a - b)(a + 2b^2)$.
21. Divide $(a^3 - 3a^2b + 3ab^2 - b^3)$ by $(a - b)$.
22. Divide $(64a^4 - 81b^6)$ by $(8a^2 + 9b^3)$
23. Divide $(a^5 - 3a^3 + a)(a)$.
24. Divide $(x^3 + 2x^2 + x)$ by $(x^2 + x)$.
25. $(a^4 + 2a^2b^2 + b^4) \div (a^2 + b^2)$.
26. $(6x^3 + 12 - 7x - x^2) \div (2x + 3)$.
27. Divide $26x^2 + 15x^3 + 10 - 39x$ by $3x - 2$.
28. What is the sum of the following polynomials?
$(-9a^3b + 6a^2b^2 - 5ab^3) + (14a^3b + 6a^2b^2 - 5ab^3) + (a^3b - 3a^2b^2 - ab^3)$

Equations

You have now learned how to do arithmetic with letters. Since many of these fundamental operations of algebra were new to you, you had a lot to learn so we did not take the time to see how they could be put to practical use in your work in electronics. Now, however, we have covered most of the elementary processes in algebra and it is time to see how to put these new mathematical tools to work in the solution of circuit problems. This can be done through the use of equations.

An equation is simply a mathematical statement that two quantities are equal to each other. The two equal quantities in an equation are called the "members" of the equation and they are always separated by an equal sign (=). Thus, the mathematical statements that $12 = 12$, $6 \times 2 = 6 \times 2$, $6 \times 2 = 12$, or $6 \times 2 = 3 \times 4$ are all equations, because the quantities on each side of the equal sign are equal to each other. Sometimes, when we want to be specific, we call the quantities on the left of the equal sign the "left member" of the equation and the ones on the right, the "right member."

Although you may already be somewhat familiar with equations and their use, it will be helpful to review some of the more common facts that you will use in working with them. Of course, the most important thing to remember is that an equation is always a statement of equality between the two members, and that in order to use it, we must never upset this equality or balance between the members. Thus, in an equation such as $24 = 24$, if we make any changes in one member, we must be very careful not to upset the balance of the whole equation. For example, we can change $24 = 24$ to $24 \times 1 = 24$, $12 \times 2 = 24$, $6 \times 4 = 24$, $6 \times 4 = 12 \times 2$, $3 \times 2 \times 4 = 6 \times 2 \times 2$, etc., because our changes do not upset the equality of the two members. Likewise, an equation such as $4Ir + 4IR = 4Ir + 4IR$ may be written in any of the following ways:

$$4(Ir + IR) = 4Ir + 4IR$$

$$4I(r + R) = 4Ir + 4IR$$

$$4I(r + R) = 4(Ir + IR)$$

because in any of these cases the equations remain balanced.

We can also do other things to equations without disturbing their equality. For example, we can add or subtract a quantity from one member of an equation as long as we perform the same operation to the other member with the same quantity. Thus, if we have an equation such as $x = x$, we can add the same number to each side without destroying the equation. For example, let's add 2 to each side of the equation $x = x$. This would give:

$$x + 2 = x + 2$$

We can see that this is still an equation, because if we let $x = 4$, and substitute for x, we have:

$$4 + 2 = 4 + 2, \text{ or } 6 = 6,$$

which is still an equation because both members are equal. Likewise, if $x = x$, we can subtract a number from either side, as:

$$x - 3 = x - 3$$

and if $x = 4$, then $x - 3 = x - 3$ becomes

$$4 - 3 = 4 - 3 \text{ or } 1 = 1$$

We can also multiply or divide both members by the same quantity. For example, if $ab = ab$ and we multiply both members by 2, we have: $2ab = 2ab$. Or, dividing by 2, we have $(ab/2) = (ab/2)$. In either case, our equality can be proved by substitution. Thus if $a = 3$ and $b = 4$, substituting in the equation $ab = ab$, $3 \times 4 = 3 \times 4$ or $12 = 12$. And, $2ab = 2ab$, or $2 \times 3 \times 4 = 2 \times 3 \times 4$, which is $24 = 24$. Likewise,

$$\frac{ab}{2} = \frac{ab}{2},$$

or

$$\frac{3 \times 4}{2} = \frac{3 \times 4}{2},$$

or

$$\frac{12}{2} = \frac{12}{2},$$

or

$$6 = 6.$$

In all of these cases our equations remain balanced, because one member always equals the other.

From this, we can make the general statement that we can do anything to one side of an equation as long as we do exactly the same thing to the other side. There is only one exception to this rule, and that is that we can never multiply or divide either member by zero. We will show you why we cannot divide by zero a little later after you have become familiar with working with equations.

These rules for working with equations are very valuable in working with formulas. Formulas are, of course, equations, but they are a special kind of equation. A formula is a rule or a law that is stated as an equation. Thus, both the equations $ab = ab$, and $E = I \times R$ are equations, but only $E = I \times R$ is a formula, because there is a law that makes it a true equation. In other words, $ab = ab$, or $I \times R = I \times R$ are equations because they meet the requirements of any equation automatically. Both members are exactly the same, and therefore equal. However, the fact that $E = I \times R$ is an equation is not apparent, and it wouldn't be recognized as an equation unless we knew that it was a statement of Ohm's Law. Here, both members are equal only by definition.

Since formulas are equations, we can use the rules for equations when working with formulas. Let's see how this can help us with a simple formula such as $P = E \times I$. Suppose we want to use this formula to find the power in a circuit, but we don't know the voltage, E. Instead of knowing the values of E and I, we have the values of I and R. Since, according to Ohm's Law, $E = I \times R$, we can substitute $I \times R$ in place of E in the power formula. Then, instead of $P = E \times I$, we would have $P = I \times R \times I$, or $P = I^2R$. By doing this, we have arranged our formula so that it contains the quantities that we know the values of, but we have not destroyed its equality. We have simply replaced one value, E, with an equal quantity, $I \times R$.

The rules for equations also help us to rearrange formulas so that they indicate directly the quantities we want to find. For example, the formula

$$Z = \sqrt{R^2 + (X_C)^2}$$

tells us how to find the impedance, Z, of a circuit. Suppose, however, we want to find X_C, but do not know the value of C or the frequency of the circuit. However, we have been given the impedance and can measure the resistance. In this case, we can apply the rules for working with equations to rearrange

$$Z = \sqrt{R^2 + (X_C)^2}$$

so that it indicates X_C from Z and R.

We do it like this:

$$Z = \sqrt{R^2 + (X_C)^2}.$$

Then, squaring both members, we have

$$(Z)^2 = \left(\sqrt{R^2 + (X_C)^2}\right)^2$$

which equals

$$Z \times Z = \sqrt{R^2 + (X_C)^2} \times \sqrt{R^2 + (X_C)^2}$$

or

$$Z^2 = R^2 + (X_C)^2$$

Now, subtracting R^2 from both members, we have

$$Z^2 - R^2 = R^2 - R^2 + (X_C{}^2)$$

or

$$Z^2 - R^2 = (X_C)^2$$

This indicates the value of $(X_C)^2$. But we want only X_C itself, so we take the square root of both members:

$$\sqrt{Z^2 - R^2} = \sqrt{(X_C)^2}$$

or

$$\sqrt{Z^2 - R^2} = X_C$$

or

$$X_C = \sqrt{Z^2 - R^2}$$

Now our one basic formula is rearranged to give us X_C directly when Z and R are known.

Likewise, C may be found with the formula $X_C = (1/2\pi fC)$ by rearrangement as follows:

If

$$X_C = \frac{1}{2\pi fC},$$

then

$$X_C \times C = \frac{1}{2\pi fC} \times C$$

or

$$X_C \times C = \frac{1}{2\pi f}.$$

Then,

$$X_C \times C \div X_C = \frac{1}{2\pi f} \div X_C$$

or

$$\frac{X_C \times C}{X_C} = \frac{1}{2\pi f X_C}$$

or

$$C = \frac{1}{2\pi f X_C}$$

Many of our formulas themselves are the result of the use of algebra and the rules for equations. They are found or derived from the knowledge of other facts.

For example, we often have the inductance of a circuit in microhenrys and the capacity in microfarads and want to find the resonant frequency of the circuit. We can do this using the formula

$$f = \frac{159}{\sqrt{LC}}$$

where L is in microhenrys, C is in microfarads, and f is in kilohertz. This formula is developed through the knowledge of other facts. For instance, at resonance we know that:

$$X_L = X_C$$

also $$X_L = 2\pi fL$$

and $$X_C = \frac{1}{2\pi fC}$$

In the formula $X_L = 2\pi fL$, f is in Hertz and L is in henrys; and in $X_C = (1 \div 2\pi fC)$, f is in Hertz and C is in farads.

Since

$$X_L = X_C,$$

We can substitute for X_L and X_C and get

$$2\pi fL = \frac{1}{2\pi fC}$$

Now, multiplying both sides by $2\pi fC$ we get

$$2\pi fL \times 2\pi fC = \frac{2\pi fC}{2\pi fC}$$

or

$$4\pi^2 f^2 LC = 1$$

Now, dividing both sides by $4\pi^2 LC$ we get

$$\frac{4\pi^2 f^2 LC}{4\pi^2 LC} = \frac{1}{4\pi^2 LC}$$

or $$f^2 = \frac{1}{4\pi^2 LC}$$

and taking the square root of both sides

$$\sqrt{f^2} = \frac{1}{4\pi^2 LC}$$

or

$$f = \frac{\sqrt{1}}{\sqrt{4} \times \sqrt{\pi^2} \times \sqrt{LC}} = \frac{1}{2\pi\sqrt{LC}}$$

$2\pi = 6.28$ and dividing 1 by 6.28 gives .159 so we can rewrite the equation as

$$f = \frac{.159}{\sqrt{LC}}$$

where f is in Hertz, L is in henrys and C is in farads.

If we substitute L in microhenrys and C in microfarads in this equation, we must divide each value by 1,000,000 to convert them to henrys and farads. Let's do this in the equation:

$$f = \frac{.159}{\sqrt{\dfrac{L}{1{,}000{,}000} \times \dfrac{C}{1{,}000{,}000}}}$$

which can be written

$$f = \frac{\dfrac{.159}{\sqrt{LC}}}{\sqrt{1{,}000{,}000^2}}$$

which is

$$f = \frac{\dfrac{.159}{\sqrt{LC}}}{1{,}000{,}000}$$

This is the same as

$$f = \frac{.159}{1} \div \frac{\sqrt{LC}}{1,000,000}$$

Now recall that to divide one fraction by another we invert the divisor and multiply. For example,

$$\frac{1}{3} \div \frac{1}{4} = \frac{1}{3} \times \frac{4}{1} = \frac{4}{3}$$

Similarly,

$$\frac{6}{14} \div \frac{1}{2} = \frac{6}{14} \times \frac{2}{1} = \frac{12}{14}$$

and

$$\frac{.159}{1} \div \frac{\sqrt{LC}}{1,000,000} = \frac{.159}{1} \times \frac{1,000,000}{\sqrt{LC}}$$

Therefore,

$$f = \frac{159,000}{\sqrt{LC}}$$

where f is in Hertz, L is in microhenrys and C is in microfarads.

To convert Hertz to kilohertz we divide by 1000. Therefore,

$$f = \frac{159,000}{\sqrt{LC}} \div 1000$$

$$f = \frac{159,000}{\sqrt{LC}} \times \frac{1}{1000}$$

$$f = \frac{159}{\sqrt{LC}}$$

where f is in kilohertz, L in microhenrys, and C in microfarads. Thus, through algebraic manipulation of letters and using the rules for equations, we derive a simple, easy-to-remember formula for finding the resonant frequency.

SHORTCUTS FOR EQUATIONS

Although we can work with any equations with the rules and information that we have already studied, there are some shortcuts which will let us work much faster and more efficiently. They are all derived from the basic rules, so we won't have to learn anything new. We will simply study the rules closely so we can see what the end results of the operations are and learn to apply them directly.

Moving a term from one member of an equation to the other member is an operation that is quite common and is called "transposing." The rule for transposing is:

A term may be transposed from one member of an equation to the other member by changing the sign of the term.

Thus, in an equation such as

$$Z^2 = R^2 + X^2$$

we can transpose the X^2 by simply changing the sign to give

$$Z^2 - X^2 = R^2$$

or transpose the R^2 to give

$$Z^2 - R^2 = X^2$$

or both, to get

$$Z^2 - R^2 - X^2 = 0$$

Using an equation with numbers shows that doing this does not destroy the equality. For example:

If

$$4 + 2 = 6,$$

then

$$4 = 6 - 2,$$

or

$$2 = 6 - 4$$

or

$$0 = 6 - 4 - 2.$$

Likewise, if

$$10 - 4 - 2 = 4,$$

then

$$10 - 4 = 4 + 2$$

or

$$10 - 2 = 4 + 4$$

or

$$10 = 4 + 2 + 4.$$

The basic rule of equations that states that we can add or subtract the same quantity from both members of the equation allows us to transpose. For example, in the equation $Z^2 = R^2 + X^2$, if we subtract X^2 from both members, we have:

$$Z^2 - X^2 = R^2 + X^2 - X^2$$
$$Z^2 - X^2 = R^2$$

Or, in the equation $10 - 4 - 2 = 4$, adding 4 to both members, we have $10 - 4 - 2 + 4 = 4 + 4$ which is equal to $10 - 2 = 4 + 4$. *Thus, transposing terms by changing the sign is simply a shortcut for adding or subtracting quantities to both members.*

Using the same basic rule, we can also make the statement that:

We can cancel out like terms from the members of an equation, if the same term appears in each member, and is preceded by the same sign.

Thus, if we have an equation like $x + y = z + y$, we can cancel the y's out to give $x = z$. Or, an equation with numbers like $4 \times 3 + 2 = 12 + 2$ can be reduced to $4 \times 3 = 12$ by canceling the 2's. As you can see, all we are doing when we cancel is to subtract the same term from both members. Thus, $x + y = z + y$ becomes $x + y - y = z + y - y$ or $x = z$. Likewise, $4 \times 3 + 2 = 12 + 2$ becomes $4 \times 3 + 2 - 2 = 12 + 2 - 2$ or simply

$$4 \times 3 = 12.$$

Another common rule is one that involves the signs of the terms in the equations. Stated simply, it is:

The signs of all the terms of an equation may be changed without changing the equality.

Thus, an equation such as $- x + y = - 4 + 3$ may be rewritten as $x - y = 4 - 3$. In doing this, we are simply multiplying both sides of the equation by the same number, -1. In our example,

$$(- x + y)(- 1) = (- 4 + 3)(- 1)$$

or

$$x - y = 4 - 3.$$

When you studied ratio and proportion, you learned to cross-multiply. Thus, $(x/y) = (a/b)$ could be rewritten as $xb = ya$. Cross-multiplication is also made possible through the rules for working with equations. When we do this, we are really multiplying both members by one term and then multiplying both members again by another term. Thus, $(x/y) = (a/b)$ becomes $xb = ya$, because: If $(x/y) = (a/b)$, then

$$b\frac{x}{y} = \frac{a}{b}b$$

or

$$\frac{xb}{y} = a.$$

Again,

$$\frac{xb}{y}y = (a)y$$

and xb = ya. Thus, cross-multiplication is just a quick way of following the basic rules.

Then, of course, we have the many operations with multiplication and division which help us so much with rearranging our formulas. For example:

$$I = \frac{E}{R} \text{ because } E = I \times R$$

and

$$\frac{E}{R} = \frac{I \times R}{R} \text{ or } \frac{E}{R} = I \text{ or } I = \frac{E}{R}.$$

Likewise,

$$R = \frac{E}{I} \text{ because } E = I \times R$$

and

$$\frac{E}{I} = \frac{IR}{I} = \frac{E}{I} = R.$$

With these rules and shortcuts in mind, and our knowledge of basic algebra, we are ready to practice solving equations.

SOLVING EQUATIONS

The purpose of learning to work with letters and equations is to make it easier to solve the problems in working in electronics. While many of the problems will be straightforward and can be solved by applying basic formulas, others will require more thinking and reasoning before the answer is found. The use of algebra and a good working knowledge of equations will be very helpful in these more difficult solutions. As you have seen, working with letters is not difficult and the rules for operating with equations are both simple and logical. However, to become really proficient with algebra and equations requires a lot of practice.

One of the biggest difficulties in arriving at circuit solutions is not in solving the equations themselves, but in setting up the equations in the first place. This also takes a lot of practice. Although it is difficult, if not impossible, to operate by a strict set of rules for solving problems, there are a few general procedures that are worth following.

First, you should read the problem so carefully that you thoroughly understand everything about it. Then, you should determine exactly what you want to know and represent it with a letter. If there are two or more unknown quantities, you should represent them in terms of the first one. Next, you should try to apply the formulas that will allow you to find the unknown quantity from the known facts. If this is not possible, you should try to set up letter equations that will allow you to state the problem in terms of the unknown quantity. Finally, you should solve the equations for the unknown value by substituting letter and number equivalents that are available. Remember, you will often save yourself a lot of time and effort by working with letters as long as possible before substituting numbers.

Now let's solve some simple equations, and later some problems, to see how we can apply these rules. In the problem

$$3i + 14 + 2i = i + 26$$

solve for i. The first thing to do is to get all like terms together. We can do this by transposing the "i" terms to one side and the numbers to the other side. Thus,

$$3i + 14 + 2i = i + 26$$

becomes

$$3i + 2i - i = 26 - 14$$

Then, collecting terms, we have: $4i = 12$ and then dividing both members by 4 to solve for i gives us

$$\frac{4i}{4} = \frac{12}{4}$$

or $i = 3$.

We can always check this answer by substituting this value of $i = 3$ back into our original equation. Doing this:

given $3i + 14 + 2i = i + 26$

then $3 \times 3 + 14 + 2 \times 3 = 3 + 26$

and $9 + 14 + 6 = 29$ or $29 = 29$

Thus, our answer of $i = 3$ must be correct because our equation is balanced if this value is used to check it.

Solve for y in the equation:

$$3(y - 2) - 10(y - 6) = 5.$$

Here, we follow the rules of order and get rid of the values within the parentheses first. This gives us:

$$3y - 6 - 10y + 60 = 5$$

Transposing:

$$3y - 10y = 5 + 6 - 60$$

Then:

$$-7y = -49$$

Changing signs:

$$7y = 49$$

Solving for y:

$$\frac{7y}{7} = \frac{49}{7}$$

or

$$y = 49 \div 7 = 7$$

Now let's try solving for E in the equation:

$$19 - 5E(4E + 1) = 40 - 10E(2E - 1)$$

Removing parentheses:

$$19 - 20E^2 - 5E = 40 - 20E^2 + 10E$$

Transposing:

$$-5E - 10E = 40 - 19$$

Then:

$$-15E = 21$$

Solving for E:

$$\frac{-15E}{-15} = \frac{21}{-15} \text{ or } E = \frac{21}{-15} = -1.4$$

Notice the cancellation of equal terms in the second step.

Earlier in our discussion of equations, we mentioned that we could never multiply or divide an equation by zero. This is easy enough to remember, but it is not always so easy to realize that we are in danger of doing it. Now that you are more familiar with working with equations, let's examine this important rule more thoroughly by working the following equation. First, let:

$$a = b$$

Multiply by a:

$$a^2 = ab$$

Subtract b^2:

$$a^2 - b^2 = ab - b^2$$

Now,

$$a^2 - b^2 = (a + b)(a - b)$$

and

$$ab - b^2 = b(a - b)$$

Therefore:

$$(a + b)(a - b) = b(a - b)$$

Divide by (a − b):

$$\frac{(a + b)\cancel{(a - b)}}{\cancel{(a - b)}} = \frac{b\cancel{(a - b)}}{\cancel{(a - b)}}$$

Then:

$$a + b = b$$

But,

$$a = b$$

Therefore:

$$2b = b$$

Divide by b:

$$\frac{2b}{b} = \frac{b}{b}$$

and

$$2 = 1.$$

Obviously, 2 cannot equal 1, and somewhere in our manipulation of the equation, we have made a mistake that has destroyed its equality. Although all of our steps seem justified, because we never did anything to one member that we didn't do to the other, we actually have divided by zero at one point. Can you find it? If a = b, then (a − b) must equal zero. Therefore, when we divided both sides of our equation by (a − b), we were dividing by zero, which we can never do.

Setting up Equations. Now let's see what sort of reasoning we have to do to set up an equation for solving a simple problem. For example, consider the following problem: "What value of inductance will produce resonance at 50 Hertz if it is placed in series with a 20 μf capacitor?" Looking at the problem carefully, we see that it deals with resonance and that a resonant frequency and a value of capacitance are given. We are asked for the inductance. Thus, we have:

Given

$$C = 20\,\mu f \quad f = 50 \text{ Hertz}$$

Find L

Since our problem deals with resonance,

we naturally think of our formula for resonance:

$$f = \frac{.159}{\sqrt{LC}}$$

Comparing this with what is given and with what we want to find, we can see that we have the necessary information to use this formula and that L can be found with it, if it is rearranged. Accordingly, we would first rearrange our formula to indicate the value of L.

Doing this:

$$f = \frac{.159}{\sqrt{LC}} \quad \text{or} \quad f^2 = \frac{.159^2}{LC}$$

then

$$Lf^2 = \frac{.159^2}{C}$$

$$L = \frac{.159^2}{f^2 C}$$

Now, we can substitute our values in the formula and solve for L. However, before we do this, we must check our units of measurement to see if the given values can be substituted directly. In this particular problem, we cannot substitute them directly because the formula $f = (.159/\sqrt{LC})$ is in kilohertz when L is in microhenrys and C is in microfarads. Therefore, we must convert 50 Hertz to kilohertz by moving the decimal three places to the left. Thus,

50 Hertz = .05 kHz

Now, using the formula

$$L = \frac{.159^2}{f^2 C}$$

$$= \frac{25{,}281}{.05 \times .05 \times 20}$$

$$= \frac{25{,}281}{.0025 \times 20}$$

$$= \frac{25{,}281}{.05}$$

= 505,620 microhenrys

= .51 henrys (approx.)

While this is a simple problem, it does show the basic reasoning behind the handling of any problem. First, examine the problem. Find a formula, if possible. Arrange the formula to indicate the unknown. Check for proper units of measurement. Substitute and solve for the unknown. Now, let's try the procedure again on a more complex situation.

In the circuit shown in Fig. 10, suppose we are asked to find the resistance of R_4 from the values given. First of all, examination of the problem shows that we are given all the resistances except R_4 and we are also given the supply voltage and the current. Listing these values, we have:

Given:

$E_T = 100V$

$I_T = .2A$

$R_1 = 100\Omega$

$R_2 = 200\Omega$

$R_3 = 800\Omega$

Find: R_4

If we had the total resistance of the circuit, we could set up an equation because we know the total resistance must be equal to R_1 plus the resistance of the parallel branch made up of R_3 in parallel with R_2 and R_4. The resistance of this branch can be expressed using the formula for parallel resistors and treating R_2 and R_4 in series like a single resistance. The resistance of the parallel branch R_p is

$$R_p = \frac{R_3(R_2 + R_4)}{R_3 + (R_2 + R_4)}$$

Thus, the total resistance of the circuit R_T is

$$R_T = R_1 + \frac{R_3(R_2 + R_4)}{R_3 + R_2 + R_4}$$

Now in this equation we do not know the value of R_T or R_4. But we do know the total voltage E_T and the total current I_T so we can find R_T.

$$R_T = \frac{E_T}{I_T}$$

Thus, it looks like we can use the equation expressing R_T in terms of R_1, R_2, R_3, and R_4 to solve for R_4. Indeed we can do this, but look at the term for the resistance of the parallel branch. Notice we have R_4 in both the top and bottom of this expression. We will have to do a great deal of manipulation before we can solve for R_4. Before we start on this task, let's look at the circuit again to see if any easier solution is available.

First, notice that the total current is .2 amp. This means that the current through R_1 is .2 amp so we can easily find the voltage drop across the resistor using:

$$E = I_T R_1$$

$$= .2 \times 100$$

$$= 20 \text{ volts}$$

If we have a source voltage of 100 volts and a voltage drop of 20 volts across R_1, we must have 100 – 20 = 80 volts across the parallel branch. Now let's find the current through R_3 which we can do using

$$I = \frac{E}{R}$$

$$= \frac{80}{800}$$

$$= .1 \text{ amp}$$

If the total current is .2 amp and .1 amp flows through one branch of the parallel circuit, the current in the other branch must also be .1 amp. Therefore we have .1 amp flowing through R_2 and R_4.

We know the voltage across R_2 and R_4 in series is 80 volts. Let's find the voltage across R_2 using:

$$E = IR_2$$

$$= .1 \times 200$$

$$= 20 \text{ volts}$$

This means the voltage across R_4 must be 80 – 20 = 60 volts. Now we know the voltage across R_4, 60 volts, and the current through it, .1 amp, so we can find R_4 using:

$$R = \frac{E}{I}$$

$$= \frac{60}{.1}$$

$$= 600 \text{ ohms}$$

Thus we have solved the problem, using a series of simple steps and avoided some complicated work by taking a second look at the problem.

In a similar fashion, we could solve for E_T if we had the following values given for the circuit in Fig. 10

Given: $R_1 = 350\Omega$

$R_2 = 300\Omega$

$R_3 = 500\Omega$

$R_4 = 600\Omega$

Find E_T if the voltage drop across R_4 is 60V.

First, since you know the voltage across R_4 and the resistance of R_4, find the current through R_4. Once you have this current you can find the voltage across R_2 because the same current flows through R_2 and R_4. When you get the voltage across R_2, you can find the current through R_3 because the voltage across R_3 will be equal to the voltage across R_2 plus the voltage across R_4.

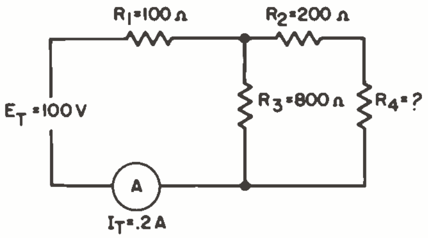


Fig. 10. Circuit used for solving for the resistance of R_4.

Now you can determine the total current flow in the circuit and then find the voltage across R_1. Once you have this voltage you should be able to find the total voltage. Work out this problem using the values given. The answer is 188 volts.

Thus, by applying the simplest formula or equation that we can, and working through the problem a step at a time, we can find the solutions to many different types of problems. As you can see, one of the greatest difficulties is in choosing a basic equation that can be made to use our known quantities. We want to be sure to choose the equation that will lead to the simplest solution. This takes sound reasoning and a lot of practice. Once you learn to do this, your knowledge of algebra and equations will let you solve the problems readily. You will get some more practice in this type of work as you study the "j" operator in the next section.

SELF-TEST QUESTIONS

29. What is an equation?
30. Which of the following can we *not* do to an equation?
    (a) Add the same number to each side.
    (b) Multiply each side by the same number.
    (c) Divide each side by 0.
    (d) Subtract the same number from each side.
    (e) Square each side.
31. What must be done to a term before it can be transposed from one side of an equation to the other?
32. What is a formula?
33. Using the power formula $P = I^2R$, solve for R.

34. Using the formula $P = I^2R$, solve for I.

35. Solve for L in the formula $X_L = 2\pi fL$.

36. Solve for f in the formula:

$$X_C = \frac{1}{2\pi fC}$$

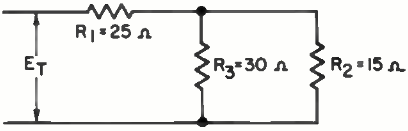
37. Solve for E using the power formula:

$$P = \frac{E^2}{R}$$

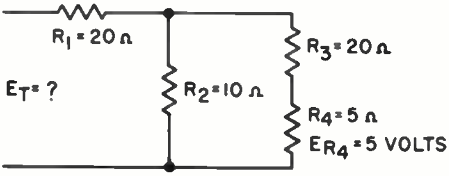
38. Solve for X_C in the formula:

$$Z = \sqrt{R^2 + (X_C - X_L)^2}$$

39. In this diagram, if the current through R_2 is 2 amps, what is the value of E_T?



40. Find the source voltage in the circuit shown.



The J Operator

The "j" operator, or j multiplier as it is sometimes called, is simply a device that allows us to represent a vector mathematically. Through the use of this j operator, we are able to simplify a great deal of work in ac circuits. Instead of having to lay out a vector accurately for each separate value of resistance or reactance, we can simply state them all mathematically and then compute their final value algebraically. This is a great advantage in dealing with the complex arrangements found in tube and transistor circuits as well as any other complex ac circuit.

Being able to compute vectors mathematically means that we can multiply and divide vectors as easily as we can add or subtract them. This in itself is something that we have never been able to do before. In this section of the lesson, we will see exactly what we mean by the term "j" and how it can be used as an operator in ac circuits. We will learn how to do j arithmetic, and then we will apply these new principles to ac circuit calculations.

NUMERICAL REPRESENTATION OF A VECTOR

When you studied vectors you learned that they could be used in electronics to represent the time or phase as well as the magnitude of ac circuit quantities. In constructing vector diagrams, we used two scales at right angles to each other, like those shown in Fig. 11. Our reference vectors were laid out from the center of the scale to the right towards 0° and were used to represent zero time or in-phase components. Those that represented quantities that led the reference vector by 90° were laid out vertically from the center towards 90°. Those that were exactly 180° out of phase were laid out on the horizontal scale, pointing from the center towards the left, or 180°. Those that represented quantities that lagged the reference vector by 90° were drawn down the vertical scale from the center towards 270°.

Thus, any vector that was laid out so that it pointed towards 90° was considered to lead a vector at 0° and lag a vector at 180°. Similarly, a vector pointing down towards 270° was considered to lag a vector at 0° and lead a vector at 180°. Because of this, we arrived at the statement that vectors could be rotated counterclockwise about a common point to indicate phase relationships or the time of an occurrence.

In this way, vector A in Fig. 11 leads 0° but lags 90°. In the same way, vector B leads 90° but lags 180°, vector C leads 180° but lags 270°, and vector D leads 270° and lags 0°.

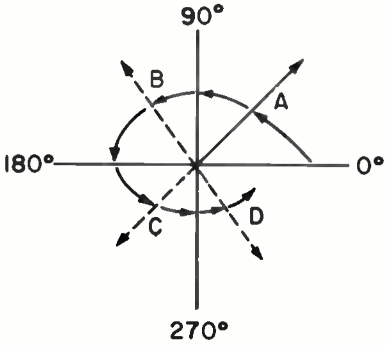


Fig. 11. Rotation of vectors.

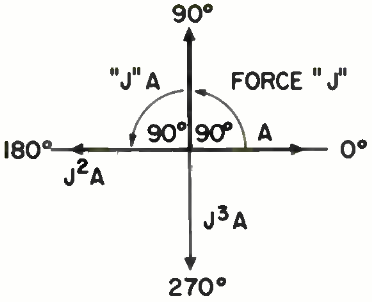


Fig. 12. Using j to rotate a vector.

In your study of algebra, you learned that you could represent any quantity or value by a letter. Therefore, let's consider that a force acts upon vectors to cause them to rotate in this way, and that this force can be represented by a letter value. Further, let's assume that the amount of this force necessary to rotate a vector 90° is represented by the letter j.

Now, let's draw a vector, A, ten units in length, along the reference line from the center toward 0° as shown in Fig. 12. In this position the vector is in phase with the reference and occurs at time zero. If we now multiply the vector by j, which represents a rotating force of 90°, we must consider that the vector will rotate 90° counterclockwise and point towards 90° as shown by vector jA in Fig. 12. Thus, multiplying the base vector A by j has resulted in its being rotated through 90° until it becomes the new vector jA.

Likewise, if we multiply our new vector jA by j, it will rotate another 90° and become vector $j \cdot jA$ or j^2A and will point toward 180° as shown. Multiplying by j again will make our vector rotate another 90° to become $j \cdot j^2A$ or j^3A pointing towards 270°. One more multiplication by j or $j \cdot j^3A$ gives us j^4A and brings the vector back to its starting point.

When we studied signed numbers, we used a horizontal scale similar to the one we use in our reference diagram for vectors. We represented positive numbers as starting from the center at 0 and working toward the right, as shown in Fig. 13. Our negative numbers started at the center and progressed toward the left. In Fig. 13, we have shown the same basic vector reference diagram as we used in Fig. 11 and 12, but we have also included the positive and negative scales along the horizontal line as shown.

Along our reference line, we have drawn vector A to represent an in-phase vector + 5 units long. If we multiply this vector A by j^2, it will rotate 180° and point towards 180° as shown. Now, according to our scale of positive and negative numbers, this new vector j^2A will equal -5. This is as it should be because anything 180° out of phase with $+5$ must be equal to -5 because it is exactly opposite. Just what is minus 5? One explanation is that minus five is plus five times minus one, because $+5 \times (-1) = -5$. If this is the case, then j^2 must be equal to -1, because $j^2 \times (+5) = -5$, just as $-1 \times (+5) = -5$.

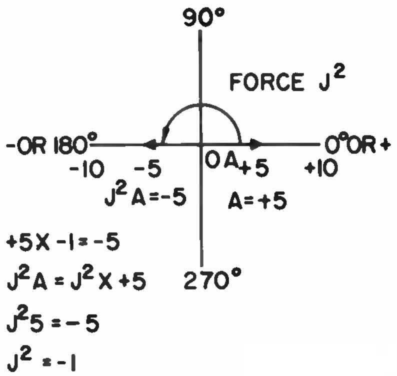


Fig. 13. Diagram of $j^2 = -1$.

Thus, any time that j^2 is used to represent a force for rotating vectors, j^2 will always be equal to -1, and -1 is substituted immediately for j^2. If $j^2 = -1$, then j must be equal to $\sqrt{-1}$. Thus, the value of j is often referred to as being imaginary because there is no number equal to $\sqrt{-1}$ because $1 \times 1 = 1$ and $-1 \times (-1)$ also $= 1$. There is no number you can multiply by itself to get -1! Whenever a j^2 term appears in a problem solution, we eliminate it by substituting -1, but where a j term appears we simply leave the j in the term because there is nothing we can substitute for it. Thus, in the term $6 + j8$, the 6 is called the real or in-phase component and the j8, the imaginary or quadrature component.

Now let's go a step further. If $j^2 = -1$, then $j \cdot j^2$ or j^3 must be equal to $-1 \cdot j$ or $-j$. We have already represented vectors drawn down the vertical line toward 270° as being a reference vector times j^3, so either j^3 or $-j$ times a vector must rotate it so that it points downward toward 270°. If $j \cdot j = j^2$ or -1 and $j \cdot j^2$ or $j^3 = j \cdot -1$ or $-j$, then j^4 representing a full 360° rotation of a vector is equal to $j^3 \cdot j$, or $j^2 \cdot j^2$ or $-1 \times (-1) = +1$. Once again this is as it should be, because any vector rotated completely around the diagram will be back where it started and represents a positive or in-phase value.

Once we understand this use of the letter "j" as an operator for determining the final position of a vector, we can use it in our work in electronics. Any time that we have a quantity multiplied by j, we will immediately know that it is a vector quantity pointing toward 90°. Similarly, if we have a $-j$ or j^3 quantity, we will know that it represents a vector drawn down towards 270°. Any positive quantity without a j or one with a j^4 multiplier can be treated as an in-phase component drawn towards 0°, and any minus quantity or one with a j^2 multiplier will represent a vector drawn out of phase towards 180°.

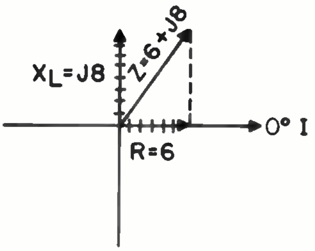


Fig. 14. Diagram of Z = 6 + j8.

Thus, if we have a series circuit consisting of a resistor and a coil, we can represent the impedance vector with a binomial term. For example, suppose the resistor has a resistance of 6Ω and the coil has an inductive reactance of 8Ω. We can say that the impedance of the circuit is equal to (6Ω + j8Ω). As soon as we see the j in the impedance notation, we can visualize a vector diagram like the one shown in Fig. 14. Here the 6Ω has no multiplier so it is drawn along the reference line I and represents the in-phase component. The j in the +j8Ω tells us that this quantity is drawn upward at right angles to the in-phase component, as shown.

Similarly, if we see a notation such as: E = (−100 − j60), we can visualize a

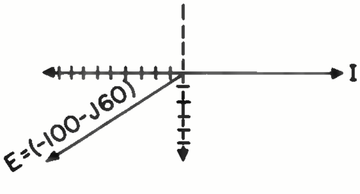


Fig. 15. Diagram of E = (−100 − j60).

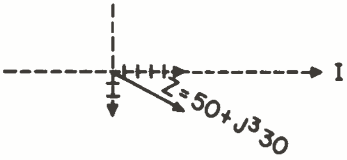


Fig. 16. Diagram of $Z = 50 + j^2 30$.

resultant voltage vector that has an E_R of −100 volts for one component and an E_{X_c} of 60 volts as another component, as shown in Fig. 15. Another vector such as

$$Z = 50 + j^3 30$$

would be immediately recognized, as shown in Fig. 16. In this way, we can represent any vector as a simple binomial term. All we have to do is remember the position values of our various j multipliers.

J ARITHMETIC

Since we are able to represent any vector mathematically as a binomial term through the use of j as a multiplier, we can solve any vector problem through the use of algebra. For example, we learned that the sum of two binomials such as (5a + 66) and (3a − 46) would be

$$5a + 66 + 3a - 46 = 8a + 20.$$

Likewise, the sum of a vector such as (10 + j5) and another equal to

$$(5 - j10)$$

would be

$$(10 + j5) + (5 - j10) = 10 + 5 + j5 - j10,$$

or a new vector equal to 15 − j5. To prove that this mathematical solution is correct we can check it against a measurement solution.

First, let's draw our two vectors, (10 + j5) and (5 − j10) as shown in Fig. 17A. Now, there are two methods which we can use to add vectors. We can break them both down into their components and add the components as we learned to do in our lesson on vectors, and as shown in Fig. 17B. Or, we can add the two vectors head to tail on the same diagram by being careful to place them in their proper position regarding the reference line, and then draw a resultant vector, as shown in Fig. 17C. In either case, the components of the resultant vector are the same and equal 15 − j5, which is exactly what we got mathematically so our mathematical solution must be correct.

To subtract one vector from another, we can also work mathematically with our binomial terms, or we can solve them with diagrams. For example, let's subtract vector B from vector A, as shown in Fig. 18. As you can see from the diagram in Fig. 18A, vector A can be written as 8 +

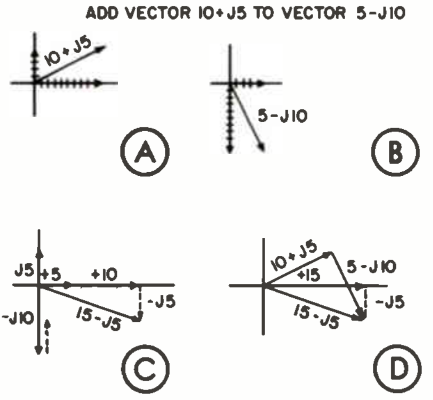


Fig. 17. Adding vectors with diagrams to prove mathematical solution.

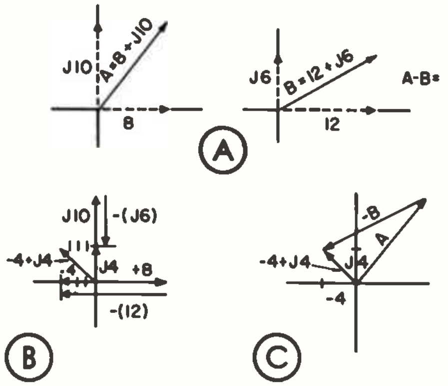


Fig. 18. Subtracting vectors with diagrams.

j10 and vector B can be written as 12 + j6. There are also two ways that we can subtract vectors with a diagram. Let's examine them.

First, there is the resolution method where we break each vector into its two components. Then we take the components of the vector that we are subtracting, reverse their directions and then add them head to tail, as we do in adding vectors. Notice how similar this is to the subtraction of signed numbers. We reverse the direction of the subtrahend (change the signs) and then proceed as in addition.

We have done this in Fig. 18B where the j6 and +12 components of vector B have been reversed in direction and then added vectorially to the j10 and +8 components of vector A. As you can see, this gives us a new vector with components of −4 and j4, or simply −4 + j4. We can also subtract vectors by subtracting them directly, as shown in Fig. 18C. Here we simply reverse the direction of vector B and add it head to tail to vector A, being careful not to change its position in regard to the reference. Then, the result drawn from the tail of A to the head of B is equal to −4 + j4, as it was with the other method.

Subtracting vectors mathematically is much simpler. We simply subtract the binomial notations of the vectors just as we would subtract any binomial terms. For example, vector B from vector A will equal:

$$(8 + j10) - (12 + j6)$$

$$= 8 + j10 - 12 - j6$$

$$= -4 + j4$$

which is the same as we got with our diagrams. This mathematical method of subtracting vectors is especially valuable in complex problems dealing with many vectors at many different angles. For example, consider the vectors A, B, C, and D in Fig. 19. Suppose we want to add vector A to vector B and then subtract vectors C and D from this sum. Mathematically this becomes:

$$(15 + j3) + (6 - j9) - (-8 + j4) - (+9 - j12)$$

$$= 15 + j3 + 6 - j9 + 8 - j4 - 9 + j12$$

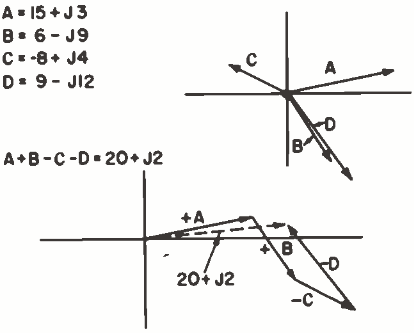


Fig. 19. Addition and subtraction of vectors by diagram.

$$= 15 + 6 + 8 - 9 + j3 + j12 - j9 - j4$$

$$= 29 - 9 + j15 - j13$$

$$= 20 + j2$$

The diagram gives us the same thing, but what a lot of work and confusion it is!

Multiplication and Division. In our work in electronics we may want to multiply or divide two or more vectors. The vectors may represent voltages, currents, or impedances of various values at different phase angles. The j operator will be very handy in this case because there is no purely graphical means of multiplying or dividing vectors with different phase angles. However, as we learned in algebra, it is quite simple to multiply or divide binomials.

Since we studied the multiplication and division of binomials earlier in this lesson, we should not have any trouble with the mathematics. Our only job now is to make sure we understand how we represent our vector resultant. Suppose that we want to multiply vector A by vector B. As shown in Fig. 20A, vector A is equal to (2 + j3) and vector B is equal to (4 + j2). To multiply these two vectors we simply multiply the binomials which gives us:

$$\begin{array}{rrr}
 & 2 + & j3 \\
\times & 4 + & j2 \\
\hline
 & 8 + & j12 \\
 & + & j4 + j^2 6 \\
\hline
 & 8 + & j16 + j^2 6
\end{array}$$

But, remember j^2 is equal to − 1, so $8 + j16 + j^2 6$ becomes

$$8 + j16 + 6(-1)$$

$$= 8 + j16 - 6$$

$$= + 2 + j16.$$

Thus, our resultant vector from this multiplication is equal to a vector of 2 + j16, as shown in Fig. 20B.

Notice that we have not only increased the length of the resultant vector by multiplying, but we have also increased the angle of this vector from the reference line. If we stop and think a moment, we will have to agree that this should happen because we are multiplying a rotating force by a rotating force when we multiply j by j. Further, remember that j alone is enough to rotate a vector 90°, while j^2 rotates it 180°. Looking at this,

$$90^\circ + 90^\circ = 180^\circ \text{ and } j \times j = 180^\circ$$

Thus, multiplying j by j is the same as adding the two 90° angles. Now, if you measure the angle that vector A makes with the reference line and add it to the angle that vector B makes with the reference line, the sum of these two angles will equal the angle of the resultant vector.

In our problem: Since $\phi A = 56^\circ$ and $\phi B = 27^\circ$, then

$$\phi A + \phi B = 56^\circ + 27^\circ = 83^\circ.$$

If we measure the angle of the resultant vector AB, we will find that its angle is exactly 83°. In addition to this relationship between the angles, there is a relationship between the lengths of vector A and vector B in the resultant vector AB. If we determine the length of vectors A and B through measurement or by using the Pythagorean theorem, we will find that A is equal to 3.61 and B is equal to

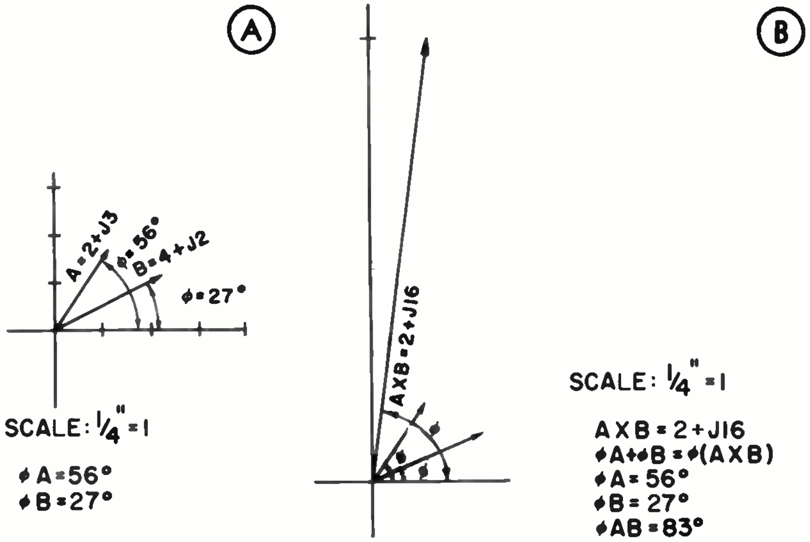


Fig. 20. Multiplying vectors.

4.47. Then if we multiply these actual lengths of A and B we find that A X B = 3.61 X 4.47 = 16.13. Now, either through measurement or by using the Pythagorean theorem, we can also determine the length of our resultant vector AB. It is equal to:

$$\sqrt{2^2 + 16^2}$$

$$= \sqrt{4 + 256}$$

$$= \sqrt{260}$$

$$= 16.13$$

to two decimal places. Thus, our resultant in vector multiplication is a new vector that is equal to the product of the length of all the vectors multiplied and that forms an angle with the reference that is equal to the sum of the angles of all the vectors multiplied. If we stop and think a moment and have understood our previous operations with vectors, we will see that this is what should happen.

In the problem that we just discussed, both of the vectors that we multiplied were made up of positive values. Let's see what happens if we multiply a vector such as 12 + j9 by another vector equal to 7 – j6. Multiplying our binomial, we have:

$$(12 + j9) \times (7 - j6)$$

$$= 84 + j63 - j72 - j^2 54$$

$$= 84 - j9 - 54(-1)$$

$$= 84 + 54 - j9$$

$$= 138 - j9$$

Here, as you can see, we had one vector to the right and above the reference, and another to the right and below the reference. The resultant is a vector that is to the right and below the reference.

Now, suppose we wanted to multiply the following vectors together:

$$(8+j16)\times(5+j2)\times(2+j3)$$

This would give us:

$$\begin{array}{r} 8+j16 \\ 5+\ \ j2 \\ \hline 40+j80 \\ +j16+j^2 32 \\ \hline 40+j96+j^2 32 \end{array}$$

Then:

$$\begin{array}{l} 40+j96+j^2 32 \\ 2+\ j3 \\ \hline 80+j192+j^2 64 \\ +\quad j120+j^2 288+j^3 96 \\ \hline 80+j312+j^2 352+j^3 96 \end{array}$$

Then:

$$\begin{aligned} & 80+j312+j^2 352+j^3 96 \\ &= 80+j312+(352\times -1) \\ &\qquad\qquad +(96\times -j) \\ &= 80-352+j312-j96 \\ &= -272+j216 \end{aligned}$$

Even though all our multipliers were to the right and above the line, our resultant is to the left and above. Notice that the j^2 term was resolved to its value of -1 and that the j^3 term resolved to its equal value of $-j$.

In order to divide vectors, we simply divide our binomial representations of the vectors involved. The easiest way to do this is to set up the division as a fraction and then clear the j term from the denominator. For example, if we wish to divide a vector such as $2+j16$ by a vector equal to $2+j3$, we would set our division up as a fraction:

$$\frac{2+j16}{2+j3}$$

Then, if we multiply both the numerator and the denominator by $2-j3$, we will not change the value of our fraction, but we will get rid of the j term in our denominator. For example, we will have:

$$\frac{(2+j16)(2-j3)}{(2+j3)(2-j3)}$$

$$=\frac{4+j26-j^2 48}{4-j^2 9}$$

$$=\frac{4+j26+48}{4+9}$$

$$=\frac{52+j26}{13}$$

$$=\frac{13(4+j2)}{13}$$

$$=4+j2$$

Thus, $2+j16\div 2+j3=4+j2$. For proof of this, check Fig. 20 again. As you can see $(4+j2)\times(2+j3)$ are the vectors we previously used in this multiplication problem and our product was $2+j16$. Similarly:

$$138-j9\div 12+j9$$

$$=\frac{138-j9}{12+j9}$$

$$=\frac{(138-j9)(12-j9)}{(12+j9)(12-j9)}$$

$$=\frac{1656-j1350+j^2 81}{144-j^2 81}$$

$$=\frac{1656-j1350-81}{144+81}$$

$$= \frac{1575 - j1350}{225}$$

$$= (7 - j6)$$

To prove our answer we simply multiply our quotient (7 – j6) by our divisor (12 + j9) to get our dividend of 138 – j9. Notice that each time we clear our j term from the denominator by multiplying our numerator and denominator by the same number. This number is always a binomial that is exactly the same as the denominator except that the sign of the j term is reversed. Such a term is called a "conjugate" term. You'll notice that each time we get a j^2 term or any even power of j, the j term disappears because $j^2 = -1$. Remember, in algebra we pointed out that $(a - b)(a + b) = a^2 - b^2$. Thus, if we have (a – jb), we can multiply it by (a + jb) to get $a^2 - j^2b^2$ and eliminate the j. Similarly, if we have a + jb, we can multiply it by a – jb to eliminate the j. Thus, we can say that we multiply both the numerator and the denominator by the conjugate of the denominator to clear the j term from the denominator.

When we multiplied two vectors together, we discovered that the product was a new vector equal in length to the product of the vector values at an angle equal to the sum of the angles of the vectors multiplied. In dividing vectors, the opposite relationship exists. If we divide one vector by another and then lay out the dividend vector, the divisor vector, and the quotient vector in a diagram, we will find that:

1. The quotient vector is equal in length to the quotient of the length of the dividend vector divided by the length of the divisor vector.

2. The quotient vector will be at an angle to the reference line that is equal to the difference between the angles of the vectors divided.

Thus, we have two ways that we can multiply or divide vectors. We can multiply or divide the binomial representation of the vectors as we have learned to do in this section, or if we know the vector length we can use it. To multiply, we find the product of the lengths and the sum of the angles. To divide, we find the quotient of the lengths and the difference of the angles.

We mentioned earlier that there was no purely graphical way to multiply and divide vectors. While we can do some of the work graphically, we must always perform some mathematics on the side. Even then, the process of finding the product or quotient in this way is very tedious and involved. Since we already have two methods for finding the products or the quotients mathematically, and since either of these methods is much simpler and faster than the simplest graphical method, it will not be worthwhile for us to study the graphical (plus some math) methods.

In this section of the lesson, you have learned to perform arithmetic operations with vectors. You have learned how to add and subtract vectors, how to multiply and divide by vectors. You will perform all four operations in solving even fairly simple ac circuit problems.

In the next section we will complete the study of the j operator and the binomial representation of vectors, by applying what you have learned to some circuit problems. To test your understanding of this chapter perform the indicated operations in the self-test questions which follow.

SELF-TEST QUESTIONS

Make the following computations:

41. (3 + j6) + (7 + j2)
42. (7 + j2) + (9 – j17)
43. (9 – j4) + (–3 + j5)
44. (8 + j3) – (4 + j7)
45. (17 – j6) – (11 – j8)
46. (3 + j7) + (8 – j13) + (7 + j8)
47. (16 – j13) + (–11 + j4) + (5 – j2)
48. (23 + j14) – (17 + j26) + (1 – j3)
49. (2 – j11) – (19 – j17) – (4 + j6)
50. (–6 – j18) – (–12 – j14) – (–2 – j21)
51. (7 + j6) (3 + j2)
52. (11 + j2) (2 – j7)
53. (–2 – j9) (–3 + j4)
54. (8 – j7) (–3 + j5)
55. (3 + j2) (4 + j6) (5 – j8)
56. (30 + j30) ÷ (4 + j2)
57. (60 – j11) ÷ (5 – j6)
58. (69 + j17) ÷ (4 – j3)
59. (44 – j168) ÷ (7 – j9)
60. 255 ÷ (6 + j7)

Using The J Operator In Circuit Operations

The best way to make sure that you understand representing vectors with binomials by using the j operator is to work with them in circuit calculations. In this way, you will get some practice with j arithmetic as well as some more experience in solving circuit problems. We will start with some simple series ac circuits, and then examine some parallel and series-parallel combinations. If, after we have done this, you feel that you still need more practice, try applying these methods to some of the ac circuits you have worked with in your other lessons.

In analyzing and working the circuit problems in this section, we will use the mathematical solutions and the j operator. However, we will still use vector diagrams to help visualize the circuit quantities and their relationships. But, since we are not going to use the diagrams for our actual calculations, we will not need to draw them to scale. Thus, for every problem, we will have a simple diagram to use in our analysis and a mathematical solution for the diagram. This is by far the best way to work with any ac circuit problem.

Series Circuits. In the circuits shown in Fig. 21 we are to find the current. Let's consider the circuit at A first. Since we have an inductance in the circuit along with a resistance, we know that the voltage will lead the current, or another way of saying the same thing is that the current will lag the voltage. Thus, since we are given the value E = 234V, and we draw it at 0°, as in Fig. 21C, then the current must lag it as shown. To position the current vector in this position, we must have a –j term in the current.

Now let's look at the circuit in Fig. 21B. Here we have a resistance and capacitance in series. We know the current must lead the voltage so we must have a phase relationship like the one shown in Fig. 21D. This means we must have a +j term in the current.

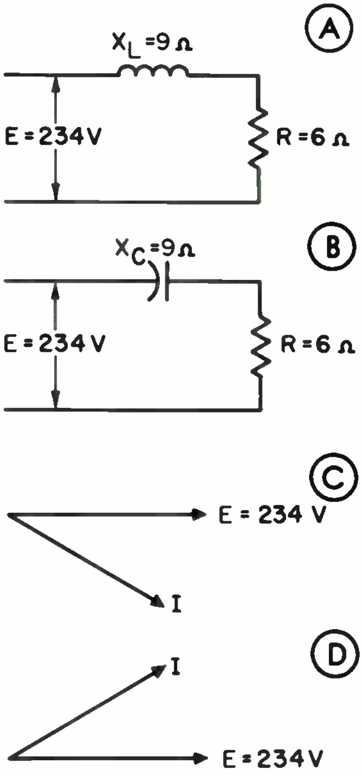


Fig. 21. The vector diagrams at C and D show the phase relationships between the voltage and current in the circuits shown at A and B.

We know that capacitive reactance is the opposite of inductive reactance so one must have a +j sign and the other a –j sign. But which should be + and which should be –? The answer is we must use the signs that make the current come out with the correct sign. Let's see what this means. We know that in an ac circuit

$$I = \frac{E}{Z}$$

In the circuits in Fig. 21 the voltage is 234 volts, the resistance 6 ohms, and the reactance 9 ohms. Thus, in one circuit Z = 6 + j9, and in the other circuit Z = 6 – j9. Now, let's solve the current in both circuits and then we can see whether a +j term represents inductive or capacitive reactance.

$$I = \frac{E}{Z}$$

$$= \frac{234}{6 + j9}$$

$$= \frac{234(6 - j9)}{(6 + j9)(6 - j9)}$$

$$= \frac{1404 - j2106}{36 - j^2 81}$$

$$= \frac{1404 - j2106}{117}$$

$$= 12 - j18$$

Now, since we already know that in the circuit with the inductive reactance we need a –j term in the current, this represents the current in Fig. 21A, and 6 + j9 must represent the impedance of the circuit in Fig. 21A. Therefore, it appears that inductive reactance should be represented by a +j term which means that capacitive reactance will be represented by a –j term. Now let's solve Fig. 21B, using 6 – j9 as the impedance, and see if we get a +j in the current term.

$$I = \frac{E}{Z}$$

$$= \frac{234}{6 - j9}$$

$$= \frac{234(6 + j9)}{(6 - j9)(6 + j9)}$$

$$= \frac{1404 + j2106}{36 - j^2 81}$$

$$= \frac{1404 + j2106}{117}$$

$$= 12 + j18$$

Thus we have a +j term in the current. In fact, notice that the only difference in the two current values is in the sign of the j term which is what we might expect since the reactances are equal.

Remember: *Inductive reactance gets a + sign and capacitive reactance a – sign.* Now, let's do another example.

In the circuit shown in Fig. 22A, we are asked to find the impedance. An examination of the circuit shows that it is a series circuit consisting of resistances, coils, and capacitors. Accordingly, we know that the impedance must be equal to the vector sum of the resistances and reactances. Therefore, in the diagram in Fig. 22B, we have made a simple sketch of the vector relationship of all the

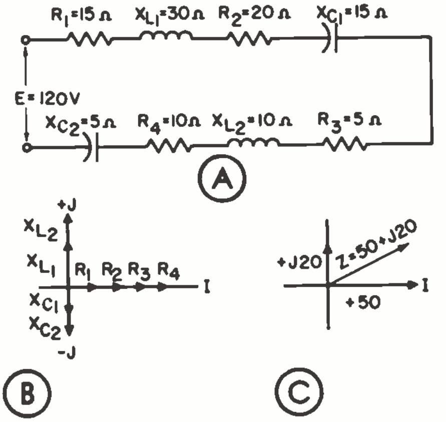


Fig. 22. Series ac circuit and vector representation.

components. Since it is a series circuit and the current is common, we have used a reference line, I, as a base for the diagram. All the resistance vectors are indicated along this reference line to show the total effect of the "in phase" components. Voltages across the resistances will all be in phase with I and hence fall along this reference vector.

The voltage across any coil in the circuit will lead the current by 90° if we neglect its resistance, so X_L vectors are drawn so that they lead the resistance vectors by 90°. This conforms with what we just discovered, that inductive reactance terms are +j terms. The voltage across the capacitors, on the other hand, will lag the current, so the X_C vectors are drawn so that they lag the resistance vectors by 90°. Now, notice that the X_C vectors are $-j$ vectors. The resistance vectors, of course, are in phase and are simply represented as the positive number terms.

Now, from our knowledge of circuit laws, vectors, algebra, and the j operator, we can write the following equation for the circuit impedance:

$$Z = R_1 + R_2 + R_3 + R_4 + jX_{L1} + jX_{L2} - jX_{C1} - jX_{C2} \text{ and,}$$

$$Z = 15 + 20 + 5 + 10 + j30 + j10 - j15 - j5$$

$$Z = 50 + j40 - j20 = 50 + j20$$

Thus, we can draw a resultant vector diagram as shown in Fig. 22C where $Z = 50 + j20$. Since the j term in our resultant vector is only used to indicate the direction of the final reactive component, or the sign of the resultant phase angle, we can drop it while we compute the impedance with our formula $Z = \sqrt{R^2 + X^2}$. Thus, the impedance is:.

$$Z = \sqrt{50^2 + 20^2}$$

$$= \sqrt{2500 + 400}$$

$$= \sqrt{2900}$$

$$= 54\Omega \text{ (approximately)}$$

Therefore, we can write the impedance of our circuit in two ways: As a vector, $Z = 50 + j20$ or from the result of our computation as: $Z = 54\Omega$ (approx).

To show that either of these answers is perfectly correct and acceptable, we can examine the circuit a little further. Suppose that we are told that the current in the circuit is equal to 4 amps and asked to find the voltage. We know that $E = IZ$, so let's substitute both of our answers for Z in this formula and see what we get. First, if $E = I \times Z$, then $E = 4 \times 54$ (approximately) or about 216 volts. Next, if $E = I \times Z$, then

$$E = 4(50 + j20) = (200 + j80) \text{ volts.}$$

Now, since $E_T = \sqrt{E_R{}^2 + E_X{}^2}$ and 200 =

E_R and j80 = E_X, we have, by dropping the j,

$$E_T = \sqrt{200^2 + 80^2}$$

$$= \sqrt{40{,}000 + 6400}$$

$$= \sqrt{46{,}400}$$

$$= 216 \text{ volts (approx.)}$$

Although either the vector representation of the answer or the numerical representation is correct and acceptable, the vector answer is often preferred as it indicates our phase angle and leading voltage. Thus, we would say that our impedance was (50 + j20)Ω and our voltage was (200 + j80)V.

Now, let's look at the circuit in Fig. 23. Here we also have a simple series circuit, and are asked to find the impedance. But, instead of being given all the resistances and the reactances, we are given an assortment of values. However, we still know that Z is equal to the sum of the resistances and the reactances, and we can draw our vector diagram as shown in Fig. 23B. Also, Z will be equal to $E_T \div I$ and E_T will be equal to the sum of the individual voltage vectors, as shown in Fig. 23C. Since we are given the total current, the frequency, some of the individual resistances or reactances, some of the voltage drops, and a value of capacitance, we can find the impedance of the circuit either way. The information given is adequate to give us anything we need to know. For example, using $Z = R \pm jX$, we have: $Z = R \pm jX = R_1 + R_2 + jX_L - j\lambda_{C1} - jX_{C2}$ and Z =

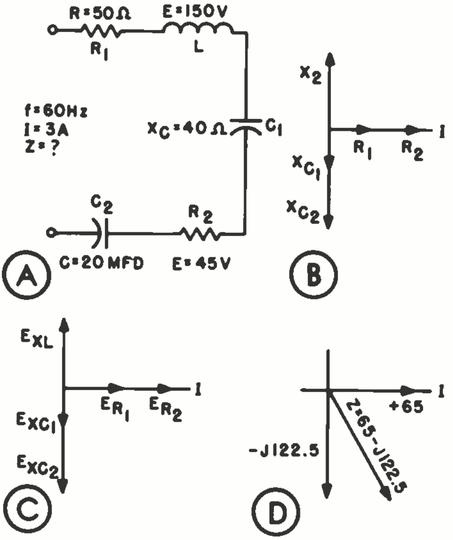


Fig. 23. Series ac circuit with vector diagrams.

$$R_1 + \frac{E_{R2}}{I} + j\,\frac{E_L}{I} - jX_{C1} - j\left(\frac{159000}{fC_2}\right)$$

Therefore,

$$Z = 50 + 15 + j50 - j40 - j\left(\frac{159000}{60 \times 20}\right)$$

and

$$\frac{159000}{60 \times 20} = \frac{1590}{12} = 132.5\Omega$$

and

$$Z = 65 + j50 - j40 - j132.5 = 65 - j122.5$$

as shown in Fig. 23D.

Using the other method, we would have:

$$Z = E_T \div I = (E_{R1} + E_{R2} + jE_{XL} - jE_{XC1} - jE_{XC2}) \div I,$$

then

$$Z = [(IR_1) + E_{R2} + jE_{XL} - j(IX_{C1}) - j(IX_{C2})] \div I$$

Now:

$$j(IX_{C2}) = [jI(159000 \div fC_2)]$$

$$= [jI(159000 \div 1200)]$$

$$= j(132.5I)$$

Thus, Z =

$$\frac{IR_1 + E_{R2} + j(E_{XL}) - j(IX_{C1}) - j(132.5I)}{I}$$

Now,

$$Z = R_1 + \frac{E_{R2}}{I} + \frac{j(E_{XL})}{I} - j(X_{C1}) - j132.5$$

$$= 50 + \frac{45}{3} + \frac{j(150)}{3} - j40 - j132.5$$

$$= 50 + 15 + j50 - j172.5$$

$$= 65 - j122.5$$

which is the same answer we got the other way. By using the Pythagorean theorem, we can further find that:

$$Z = \sqrt{65^2 + 122.5^2}$$

$$= \sqrt{4225 + 15006}$$

$$= \sqrt{19231}$$

$$= 139\Omega \text{ (approximately)}$$

Notice that we always drop the j when we use the Pythagorean theorem, because the j only indicates the position of the impedance vector and there is no way to indicate this in a monomial such as 139. However, we can use the sign of the j operator to indicate the direction by saying "139Ω capacitive."

Parallel Circuits. In our earlier ac circuit calculations, we have worked almost exclusively with series circuits. Although parallel circuits and series-parallel circuits can be solved by using vector measurement solutions alone, the vector diagrams generally become quite complex and difficult to work with. However, now that we have a method of solving ac circuits mathematically, we shall be able to handle these more complex circuits.

The major difference in working with parallel circuits is in the choice of a reference. In your study of dc circuits, you learned that the current divides in the branches of a parallel circuit while the voltage across all the branches is common. This is just the opposite from a series circuit where the current is common and the voltage divides. The same is true for ac circuits, so the general rules for dc circuits will apply to ac circuit solutions. Therefore, in our work with ac parallel circuits, we will use the circuit voltage as a reference instead of the current as we did in most of the series circuits. This difference in the choice of the reference value is very important.

Now, let's look at the simple parallel circuit in Fig. 24. Here, our circuit contains a coil in one leg and a resistor in the other leg. The voltage applied to the circuit is applied equally to each branch. However, the current as shown by an ammeter in each leg is different in each branch. The total current in the circuit is equal to the sum of the current in the branches. What is this total current?

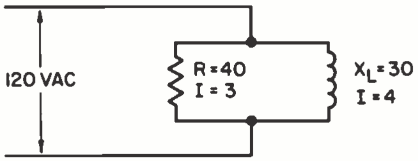


Fig. 24. Simple ac parallel circuit.

Since one branch has an inductive current and the other branch has a resistive current, we cannot add the two currents together numerically. We must add them together vectorially just as we would the voltages in a series circuit. If we draw a vector diagram for this addition, we have to use the voltage as our reference line since the voltage across each branch is the same. Thus, we would lay out our reference line and label it E as shown in Fig. 25A. Next, we want to represent our current vectors for each leg. First, we take a vector representing the current in the resistance branch and draw it along the reference line, E, and label it I_R, as shown in Fig. 25B. We draw this vector along the reference to show that the current through the resistive branch is in phase with the common voltage.

Next, we want to represent the current through our inductive branch as a vector. Now, we know that neglecting the resistance of the coil, this current will lag the voltage by exactly 90°. Since our E reference is along the horizontal and points to the right, we must draw this current vector downward, as shown in Fig. 25C, in order to show this lagging effect. Thus, our I_L vector is a $-j$ value. Therefore, our total current vector for the circuit would be indicated mathematically as

$$I_T = I_R - jI_L,$$

as shown in Fig. 25C.

Now, if we substitute the given values for the two currents shown in Fig. 24, our total current would equal:

$$I_T = I_R - jI_L$$

$$= 3 - j4$$

dropping the j

$$I_T = \sqrt{3^2+4^2}$$

$$= \sqrt{9+16}$$

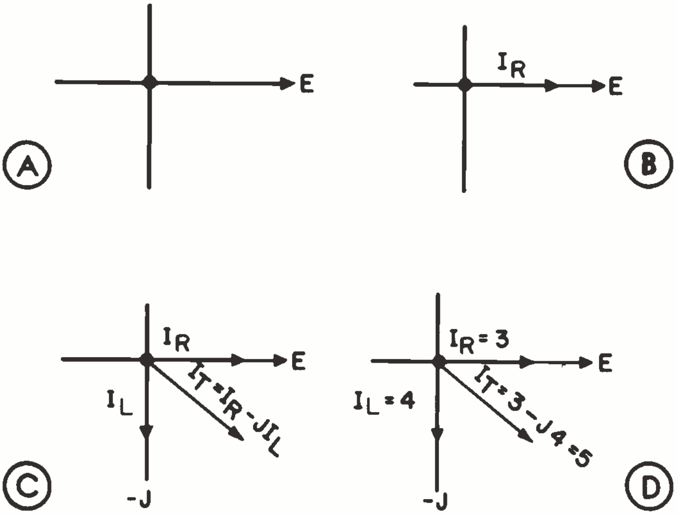


Fig. 25. Parallel circuit solution.

$$= \sqrt{25}$$

$$= 5 \text{ amps}$$

Our j operator was minus, so our total circuit current is 5 amps (lagging) as shown by the vector $I_T = 3 - j4 = 5$, in Fig. 25D.

If we want to find the impedance of this parallel circuit, we can proceed in two ways. The simplest way is to use the total current and the applied voltage in our formula E = IZ and therefore Z = (E/I) or, in our circuit, Z = (120/5) = 24Ω. If we were relying on only vector measurement solutions for parallel circuits, this would be the only way we could find the impedance. The reason for this is that the formula for resistances or impedances in parallel is

$$Z_T = \frac{Z_1 \times Z_2}{Z_1 + Z_2}$$

and we have no purely graphical way of multiplying or dividing the vectors.

However, since we know how to use the j operator, we can multiply or divide these vectors mathematically. Therefore, we can use this formula to find the total impedance. In the circuit shown in Fig. 24, we would have:

$$Z_T = \frac{R(jX_L)}{R + jX_L}$$

$$= \frac{40(j30)}{40 + j30}$$

$$= \frac{j1200(40 - j30)}{(40 + j30)(40 - j30)}$$

$$= \frac{j48000 - j^2 36000}{1600 - j^2 900}$$

$$= \frac{j48000 + 36000}{1600 + 900}$$

$$= \frac{j480 + 360}{25}$$

$$= 14.4 + j19.2$$

and our impedance total written as a vector would be (14.4 + j19.2). Then, applying the Pythagorean theorem to this vector, we would find:

$$Z = \sqrt{(14.4)^2 + (19.2)^2}$$

$$= \sqrt{207.36 + 368.64}$$

$$= \sqrt{576} = 24\Omega$$

This, of course, is the same answer that we got for the impedance by dividing the total voltage by the total current.

While the impedance of any parallel circuit can be found using either method, you can see that it is much simpler and quicker to use the first method. The current can be found by addition of vectors and then a simple division allows us to find the impedance if we know the voltage. The other way requires both the multiplication and division of vectors which can become quite complex. In fact, in complex circuits, it becomes so involved mathematically that it is almost never used.

Because of this complexity, a method of finding impedance has been worked out that involves the addition of current vectors, even though the voltage is not known. For example, consider the circuit in Fig. 26. Here we have a resistor, a coil, and a capacitor in parallel. We are asked to find the impedance and we have the values of X_C, X_L, and R given. Since we have no values of either current or voltage

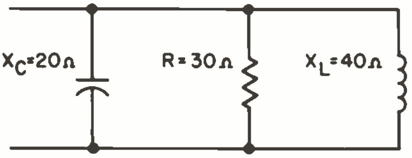


Fig. 26. Parallel circuit with X_C, R_1, and X_L. Find Z.

given, it would seem that we will be forced to use our impedance formulas.

Suppose, however, that we *assume* a circuit voltage of 120 volts. If we do this, then we can find the current that would flow in each branch with this assumed voltage applied to the circuit. It would be:

$$I_C = \frac{E}{X_C} = \frac{120}{20} = 6 \text{ amps}$$

$$I_R = \frac{E}{R} = \frac{120}{30} = 4 \text{ amps, and}$$

$$I_L = \frac{E}{X_L} = \frac{120}{40} = 3 \text{ amps.}$$

Now, we can add these currents using the j operator to find the total current that would flow for the value of assumed voltage we have chosen.

Laying out a vector diagram for reference as shown in Fig. 27, we would use our common reference E as a base. Then our I_L vector would be drawn down toward –j to indicate the current lag through the coil. The vector for I_C would be drawn up toward +j, indicating the leading current through the capacitor. Finally, the I_R vector would be drawn along the reference to indicate the in phase current through the resistance. Now, our problem becomes mathematically:

$$I_T = I_R + jI_C - jI_L$$

$$= 4 + j6 - j3$$

$$= 4 + j3$$

Then,

$$I_T = \sqrt{4^2 + 3^2}$$

and I_T = 5 amps leading (notice the sign of j) with an assumed voltage of 120 volts.

Now, applying our formula Z = (E/I), we have Z = (120/5) = 24Ω. Thus, an assumed voltage forces a total current through the circuit that gives us an impedance of 24Ω. The interesting thing is, that no matter what voltage we assume, the computed current will always be a value such that our impedance for this circuit will work out to 24Ω. Thus, we can assume any voltage for a parallel circuit, compute the total current forced

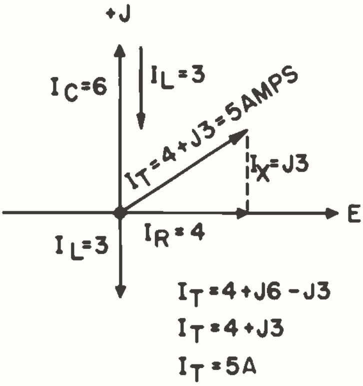


Fig. 27. Vector solution of I for circuit in Fig. 26.

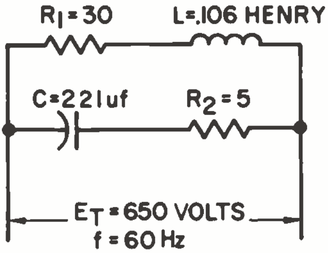


Fig. 28. Series-parallel ac circuit.

through the circuit by this voltage, and then divide to find the impedance. Naturally, in doing this, we always assume a value of voltage that will make our problem as simple as possible. Try assuming a couple of different voltages for the circuit in Fig. 26, and then compute the current and impedance. You will see that 24Ω is always your answer for this circuit.

Series-Parallel Circuits. The next problem is to learn to combine our knowledge of series circuits with our knowledge of parallel circuits for series-parallel combinations. Generally, we do this just as we would for dc circuits. We break our circuit down into simple circuits which we solve one at a time, and then combine our answers. For example, let's consider the circuit shown in Fig. 28.

Here we have a coil in series with a resistor in one branch which is in parallel with another branch containing a resistor and a capacitor. We are given R_1, R_2, L and C, the total voltage, and the frequency. We are asked to find the total current and the total impedance of the circuit. First solve each of the two branches separately, then combine them to find the total current, and then find the total impedance.

The best way is to proceed as follows: Let's call the branch with the coil, branch A, and the one with the capacitor, branch B. Since we want the total current, we would want to find the current in each leg and then combine them. Starting with branch A, we must first find X_L and then find I_A as follows:

$$\begin{aligned}
I_A &= E_A \div Z_A \\
&= E_A \div (R_1 + jX_L) \\
&= E_A \div (R_1 + j2\pi fL) \\
&= 650 \div (30 + j6.28 \times 60 \times .106) \\
&= 650 \div (30 + j40) \\
&= \frac{650\,(30 - j40)}{(30 + j40)\,(30 - j40)} \\
&= \frac{19500 - j26000}{900 - j^2\,1600} \\
&= \frac{195 - j260}{9 + 16} \\
&= \frac{195 - j260}{25} \\
&= 7.8 - j10.4
\end{aligned}$$

Now, notice that I_A is the current through the series circuit of branch A, yet we have it broken up into a j binomial. This probably seems strange since you know that the current is common in a series circuit and the current through the coil is the same as the current through the resistance. Although it is true that we have only one current through the series branch, this current is made up of the combined effects of the resistor and the coil. Therefore, this current is a vector that can be considered to consist of two components just the same as any other vector.

The vector diagrams in Fig. 29 may help you to understand this. In Fig. 29A we have shown the impedance vector 30 + j40 which we found in the first few steps of our equation. Since this is a series circuit, we have used the current as a

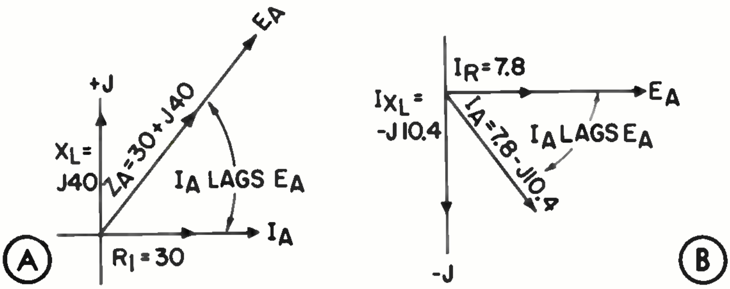


Fig. 29. Vector relationships for branch A. (Not to scale.)

reference for this diagram. Now, if we were to represent the voltage for this series circuit vectorially, it would extend along the same line as the impedance vector, as shown. Thus, the vector diagram in Fig. 29A shows the relationships of the impedance, the current, and the voltage. Notice that the current lags the voltage.

Now, when we get ready to combine branch A and branch B, we will want to use the voltage as a reference because it is common to both branches. When we do this, we would have to show the current for branch A as a vector lagging the voltage, as shown in Fig. 29B. Thus, either Fig. 29A or 29B shows the proper relationship between the current and the voltage. In order to compute with this current vector using the j operator, we would want to break it up into its components. We can do this in the diagram, shown in Fig. 29B, because E is the reference. That is why we simply divided the voltage E_A by the binomial of the impedance vector rather than solving for the monomial impedance. In this way, our current is already broken into its binomial term, ready for use in combining with branch B as soon as we divide the voltage by the impedance.

Now, we follow the same general procedure and solve for the current in branch B as follows:

$$I_B = E_B \div Z_B$$

$$= E_B \div (R_2 - jX_C)$$

$$= E_B \div \left(R_2 - j\frac{159000}{fC}\right)$$

$$= 650 \div \left(5 - j\frac{159{,}000}{60 \times 221}\right)$$

$$= 650 \div (5 - j12)$$

$$= \frac{650\,(5 + j12)}{(5 - j12)\,(5 + j12)}$$

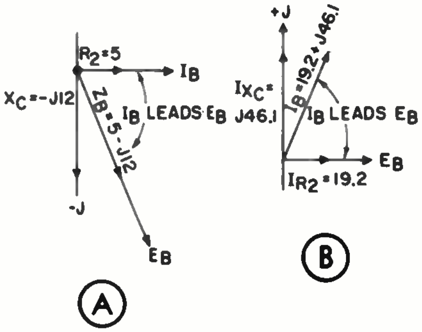


Fig. 30. Vector relationships for branch B. (Not to scale.)

$$= \frac{3250 + j7800}{25 - j^2 144}$$

$$= \frac{3250 + j7800}{25 + 144}$$

$$= \frac{3250 + j7800}{169} = 19.2 + j46.1$$

The vector diagrams for this are shown in Fig. 30 in the same manner as those in Fig. 29. Notice that in the diagram in Fig. 29A, the inductive terms are positive or +j to show that the voltage leads the current reference. However, when we use the voltage as a reference, as in Fig. 29B, the current term must be negative, or –j, in order to show this same lag. Likewise, the sign changes in Fig. 30A and 30B show the same thing except that they are opposite because we are dealing with capacitance or leading current.

Now that we have found the current in the two branches, we simply add them as shown by the vector diagram in Fig. 31 and the following mathematical solution:

$$I_T = I_A + I_B$$

$$= (7.8 - j10.4) + (19.2 + j46.1)$$

$$= 7.8 + 19.2 + j46.1 - j10.4$$

$$= 27 + j35.7$$

$$= \sqrt{27^2 + 35.7^2}$$

$$= \sqrt{729 + 1274.5}$$

$$= \sqrt{2003.5}$$

$$= 44.7 \text{ amps}$$

Now, the impedance is:

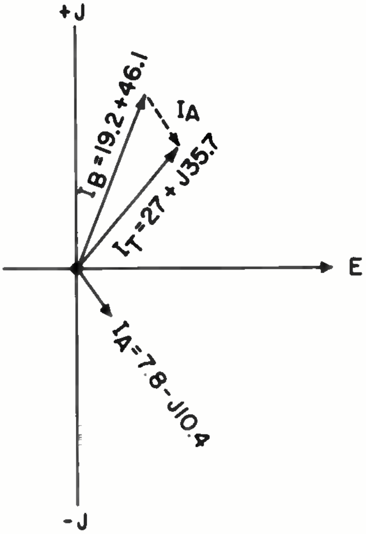


Fig. 31. Vector addition of current in Figs. 25 and 26 (not to scale).

$$Z = \frac{E}{I} = \frac{650}{44.7} = 14.5 \text{ ohms}$$

In solving circuit problems such as this it is wise to set up a complete equation in the beginning. In this way you get straight to the heart of the problem and save yourself from doing a lot of work finding things that you do not need. As an example, we found only the binomial expressions for current and impedance in the circuit we just completed. We did not bother to find the numerical values of the quantities until the last moment. Also, we did not have to find the voltage drops across the individual components. The proper circuit equations will keep you from spending unnecessary time solving for quantities you do not need. Stated as a complete equation, this last circuit would have been:

Given: $E_T = 650V$

$f = 60$ Hertz

$R_1 = 30\Omega$

$R_2 = 5\Omega$

$L = .106\text{h}$

$C = 221\ \mu\text{f}$

find $I_T\ Z_T$
Then,

$$Z_T = \frac{E_T}{I_T}$$

and

$$I_T = I_A + I_B$$

Therefore:

$$Z_T = E_T \div (I_A + I_B)$$

But: $I_A = E_A \div Z_A$

$I_B = E_B \div Z_B$

But: $E_B = E_A = E_T$

Then

$I_A = E_T \div Z_A$

$I_B = E_T \div Z_B$

Therefore:

$$Z_T = \frac{E_T}{\dfrac{E_T}{Z_A} + \dfrac{E_T}{Z_A}}$$

Now: $Z_A = R_1 + jX_L$
$Z_B = R_2 - jX_C$

Therefore:

$$Z_T = \frac{E_T}{\dfrac{E_T}{R_1 + jX_L} + \dfrac{E_T}{R_2 - jX_C}}$$

And: $jX_L = j(2\pi fL)$
$jX_C = j(159000 \div fC)$

Therefore:

$$Z_T = \frac{E_T}{\dfrac{E_T}{R_1 + j2\pi fL} + \dfrac{E_T}{R_2 - j\dfrac{15900}{f_C}}}$$

This is the complete circuit equation and gives us Z_T in terms of our known values. We can now solve for Z_T and apply the Pythagorean theorem to get Z_T as a monomial answer. Ohm's Law will then give us I_T.

In Fig. 32, we have a more complex series-parallel circuit. In this problem, the resistances and reactances are given; you are to find the total circuit impedance.

Examination of the circuit will show that the total impedance "Z_T" is equal to the vectorial sum of R_1 X_{L1} and X_{C1} in series with the combined impedance of the three parallel branches. For con-

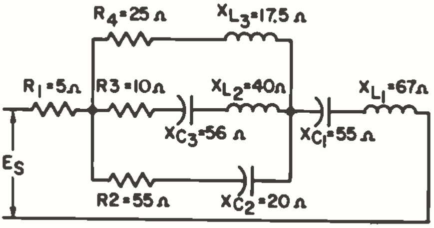


Fig. 32. Series-parallel circuit problem.

venience, we will refer to the combined impedance of the three parallel branches as "Z_b". We can now write the equation for the total circuit impedance:

$$Z_T = (R_1 + jX_{L1} - jX_{C1}) + Z_b$$

We will first find the value of Z_b. Later, we can find the total circuit impedance.

Neither the source voltage E_S nor the voltage drop across any part of the circuit is given. However, we can simplify the work by assuming that a voltage "E_b" exists across the three parallel branches and use this voltage as a reference. Now, we can write the equation:

$$Z_b = \frac{E_b}{I_b}$$

where I_b is the total current flowing in the three parallel branches. Regardless of the assumed voltage E_b, the impedance of the parallel branches will remain the same since the current is proportional to E_b divided by Z_b.

The current I_b is the vectorial sum of the currents flowing through the three individual parallel branches. We will use I_1 to represent the current through R_2 and X_{C2}, I_2 for the current through R_3, X_{C3} and X_{L2}, and I_3 to represent the current through R_4 and X_{L3}. Then, we can write:

$$I_b = I_1 + I_2 + I_3$$

Substituting this in the equation for the impedance of the parallel branches gives us:

$$Z_b = \frac{E_b}{I_1 + I_2 + I_3}$$

The current flowing through each of the parallel branches is equal to the assumed voltage divided by the impedance of the individual branches. The branch currents then are:

$$I_1 = \frac{E_b}{Z_1} \quad I_2 = \frac{E_b}{Z_2} \quad I_3 = \frac{E_b}{Z_3}$$

We can now write the equation for the combined impedance of the parallel branches:

$$Z_b = \frac{E_b}{\dfrac{E_b}{Z_1} + \dfrac{E_b}{Z_2} + \dfrac{E_b}{Z_3}}$$

Let us assume that E_b is equal to 100V (we can assume any value for E_b and still get the same final answer for Z_b) and substitute 100 for E_b in the equation:

$$Z_b = \frac{100}{\dfrac{100}{55 - j20} + \dfrac{100}{10 + j40 - j56} + \dfrac{100}{25 + j17.5}}$$

$$Z_b = \cfrac{100}{\left(\cfrac{100}{55 - j20} \cdot \cfrac{55 + j20}{55 + j20}\right) + \left(\cfrac{100}{10 - j16} \cdot \cfrac{10 + j16}{10 + j16}\right) + \left(\cfrac{100}{25 + j17.5} \cdot \cfrac{25 - j17.5}{25 - j17.5}\right)}$$

$$Z_b = \cfrac{100}{\cfrac{100(55 + j20)}{3025 - j^2 400} + \cfrac{100(10 + j16)}{100 - j^2 256} + \cfrac{100(25 - j17.5)}{625 - j^2 306}}$$

Now, since $j^2 = -1$

$$Z_b = \cfrac{100}{\cfrac{100(55 + j20)}{3025 + 400} + \cfrac{100(10 + j16)}{100 + 256} + \cfrac{100(25 - j17.5)}{625 + 306}}$$

$$Z_b = \cfrac{100}{\cfrac{5500 + j2000}{3425} + \cfrac{1000 + j1600}{356} + \cfrac{2500 - j1750}{931}}$$

$$Z_b = \frac{100}{(1.6 + j.58) + (2.8 + j4.5) + (2.7 - j1.88)}$$

$$Z_b = \frac{100}{7.1 + j3.2}$$

$$Z_b = \frac{100}{7.1 + j3.2} \cdot \frac{7.1 - j3.2}{7.1 - j3.2}$$

$$Z_b = \frac{710 - j320}{60.2}$$

$$Z_b = 11.8 - j5.3\Omega$$

Now solve for the total circuit impedance:

$$Z_T = (5 + j67 - j55) + (11.8 - j5.3)\Omega$$

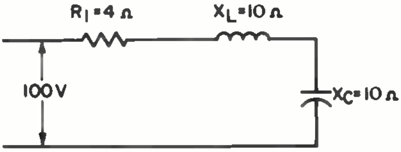
$$Z_T = 16.8 + j6.7\Omega$$

Then from the Pythagorean theorem, the total circuit impedance is equal to 18.1 ohms.

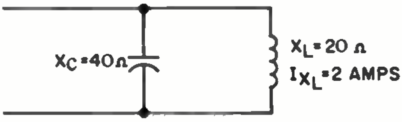
In this lesson, we have studied two math subjects that will be especially important in your work in electronics — algebra and the j operator. With a knowledge of these two subjects, you will be able to resolve complex ac circuit vectors mathematically. As you can see, this is a far more accurate and less tedious method than solving these problems by laying out and measuring vectors. However, we are still missing one very important factor of ac circuits. We are able to determine whether the current leads or lags the voltage, but we cannot tell what the actual phase angle is by mathematics alone. The only way we can determine the phase angle is to draw our final vector resultant to scale and then measure the angle of lead or lag with a protractor. In our next reference lesson on mathematics, we will learn how to compute the phase angle mathematically and then go on to consider power and resonance in ac circuits in more detail.

SELF-TEST QUESTIONS

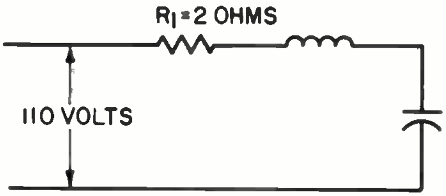
61. One leg of a parallel circuit contains an impedance equal to (3 + j4), the other leg impedance equals (8 – j6). What is the total impedance of the circuit?
62. If the impedance vector of a series circuit equals 40 – j30 and the applied voltage is 100 volts, what is the current in amps?
63. A series circuit consists of R_1, R_2, R_3, C_1, C_2, L_1, and L_2 connected in series. What is the impedance of the circuit if $R_1 = 12$ ohms, $R_2 = 17$ ohms, $R_3 = 11$ ohms, $X_{C1} = 75$ ohms, $X_{C2} = 50$ ohms, $X_{L1} = 40$ ohms, and $X_{L2} = 60$ ohms?
64. What is the total impedance of a series circuit that contains the following impedances: 1 + j6, 3 – j2, 4 – j7, 3 + j14, 7 – j1?
65. In the circuit shown find the total current, the voltage across the coil, and the voltage across the capacitor. What is the name given to this type of circuit?



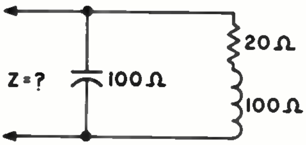
66. If an alternating voltage of 117 volts is connected across a parallel circuit made up of three legs, with a 30Ω resistance in one leg, an inductive reactance of 117Ω in one leg, and a capacitive reactance of 39Ω in one leg, what is the total current drawn from the source?
67. A parallel circuit is made up of four branches, three of the four branches being pure resistances of 16, 16, and 8 ohms, respectively. The fourth branch has an inductive reactance of 6Ω. What is the total impedance of the circuit?
68. A series circuit consisting of a 12-ohm resistor, a 20-mfd capacitor and a .1 henry coil is connected across a 150-volt, 120-Hertz ac source. What is the current in the circuit?
69. Find the current through the capacitor in the circuit shown.



70. What will the current be in the circuit shown when it is operated at its resonant frequency?



71. Find the impedance of the circuit shown below.



Answers To Self-Test Questions

1. A monomial is a mathematical expression containing only one term.
2. A polynomial is a mathematical expression containing two or more terms.
3. A binomial contains two terms while a trinomial contains three terms.
4. An exponent is a number which is normally placed to the right and above a term. It means the number of times the term is to be multiplied by itself.
5. 6.

6.
$$\begin{array}{rr} 3a^2b & +\,2b \\ a^2b & -\;\;b \\ -2a^2b & +\,4b \\ \hline 2a^2b & +\,5b \end{array}$$

7. (a) $7x^2y + 12xy + 3y + 2$

(b) $-6a^4b^2 - 2$

8.
$$\begin{array}{rrrrrr} 4a^2b^2 & & & & -\,2b & \\ & & +\,3ab^2 & +\,2a & & \\ a^2b^2 & -\,3a^2b & & & +\,3b & +\,3 \\ \hline 5a^2b^2 & -\,3a^2b & +\,3ab^2 & +\,2a & +\;b & +\,3 \end{array}$$

9. (a) $3ab - 3a - 3$

(b) $4x^2y + 4xy + 3y$

10.
$$\begin{array}{rrrrr} ab^2 & +\;ab & -\,3a & -\,b & \\ & & +\;a & +\,b & \\ 3ab^2 & & & -\,b & \\ & +\;ab & +\,7a & & \\ & +\;ab & & & +\,3 \\ \hline 4ab^2 & +\,3ab & +\,5a & -\,b & +\,3 \end{array}$$

11.
$$\begin{array}{rrr} 11a & +\;b & -\,2c \\ -\;\;6a & +\,4b & -\,2c \\ \hline 5a & +\,5b & -\,4c \end{array}$$

12.
$$\begin{array}{rrrr} a^3 & -\;a^2b & +\,4ab^2 & \\ & -\,6a^2b & -\,3ab^2 & +\,b^3 \\ \hline a^3 & -\,7a^2b & +\;ab^2 & +\,b^3 \end{array}$$

13.
$$\begin{array}{rrrr} 3a & -\,4b & +\,c & -\,6d \\ -\,a & -\;b & -\,c & -\;d \\ \hline 2a & -\,5b & & -\,7d \end{array}$$

14.
$$\begin{array}{rr} 2a & +\,6b \\ -4a & -\,7b \\ \hline -2a & -\;b \end{array}$$

15.
$$\begin{array}{rrrr} 8a^3 & +\,3a^2b & -\;ab^2 & +\;b^3 \\ -6a^3 & +\;a^2b & -\;ab^2 & +\;b^3 \\ \hline +2a^3 & +\,4a^2b & -\,2ab^2 & +\,2b^3 \end{array}$$

16.
$$\begin{array}{rrr} a & +\,2b & \\ a & -\;b & \\ \hline a^2 & +\,2ab & \\ & -\;ab & -\,2b^2 \\ \hline a^2 & +\;ab & -\,2b^2 \end{array}$$

17.
$$\begin{array}{rrrr} a^2 & +2ab & +b^2 & \\ & a & +b & \\ \hline a^3 & +2a^2b & +\;ab^2 & \\ & a^2b & +2ab^2 & +b^3 \\ \hline a^3 & +3a^2b & +3ab^2 & +b^3 \end{array}$$

18. $(2a + 3b)(2a - 3b) = 4a^2 - 9b^2$

19.
$$\begin{array}{rrrr} a^2 & -2ab & +b^2 & \\ & a & +b & \\ \hline a^3 & -2a^2b & +\;ab^2 & \\ & a^2b & -2ab^2 & +b^3 \\ \hline a^3 & -\;a^2b & -\;ab^2 & +b^3 \end{array}$$

20.
$$\begin{array}{l}
a - \quad b \\
\underline{a + \;2b^2} \\
a^2 - ab \\
\underline{\qquad\quad + 2ab^2 - 2b^3} \\
a^2 - ab + 2ab^2 - 2b^3
\end{array}$$

21.
$$\begin{array}{r|l}
 & a^2 - 2ab + b^2 \\
\hline
a - b & a^3 - 3a^2b + 3ab^2 - b^3 \\
 & \underline{a^3 - a^2b} \\
 & \quad - 2a^2b + 3ab^2 \\
 & \quad \underline{- 2a^2b + 2ab^2} \\
 & \qquad\qquad ab^2 - b^3 \\
 & \qquad\qquad \underline{ab^2 - b^3}
\end{array}$$

or $(a - b)^2$

22. $$\frac{64a^4 - 81b^6}{8a^2 + 9b^3}$$

$$= \frac{(8a^2 + 9b^3)(8a^2 - 9b^3)}{8a^2 + 9b^2}$$

$$= 8a^2 - 9b^3$$

23. $$\frac{a^5 - 3a^3 + a}{a}$$

$$= \frac{a(a^4 - 3a^2 + 1)}{a}$$

$$= a^4 - 3a^2 + 1$$

24. $$\frac{x^3 + 2x^2 + x}{x^2 + x}$$

$$= \frac{x(x^2 + 2x + 1)}{x(x + 1)}$$

$$= \frac{(x + 1)(x + 1)}{x + 1}$$

$$= x + 1$$

25. $$\frac{a^4 + 2a^2b^2 + b^4}{a^2 + b^2} = \frac{(a^2 + b^2)(a^2 + b^2)}{a^2 + b^2}$$

$$= a^2 + b^2$$

26.
$$\begin{array}{r|l}
 & 3x^2 - 5x + 4 \\
\hline
2x + 3 & 6x^3 - x^2 - 7x + 12 \\
 & \underline{6x^3 + 9x^2} \\
 & \qquad -10x^2 - 7x \\
 & \qquad \underline{-10x^2 - 15x} \\
 & \qquad\qquad + 8x + 12 \\
 & \qquad\qquad \underline{+ 8x + 12}
\end{array}$$

27.
$$\begin{array}{r|l}
 & 5x^2 + 12x - 5 \\
\hline
3x - 2 & 15x^3 + 26x^2 - 39x + 10 \\
 & \underline{15x^3 - 10x^2} \\
 & \qquad + 36x^2 - 39x \\
 & \qquad \underline{+ 36x^2 - 24x} \\
 & \qquad\qquad - 15x + 10 \\
 & \qquad\qquad \underline{- 15x + 10}
\end{array}$$

28.
$$\begin{array}{l}
- \;\;9a^3b + 6a^2b^2 - 5ab^3 \\
+ 14a^3b + 6a^2b^2 - 5ab^3 \\
\underline{+ \;\;\;a^3b - 3a^2b^2 - \;ab^3} \\
+ \;\;6a^3b + 9a^2b^2 - 11ab^3
\end{array}$$

29. An equation is a mathematical statement that two quantities are equal to each other.

30. (c) Division by 0 can not be done in mathematics.

31. The sign of the term must be changed.

32. A formula is a rule or law which is stated as an equation.

33. $$R = \frac{P}{I^2}$$

34. $$I = \sqrt{\frac{P}{R}}$$

35. $L = \dfrac{X_L}{2\pi f}$

36. $f = \dfrac{I}{2\pi C X_C}$

37. $E = \sqrt{PR}$

38. $X_C = X_L + \sqrt{Z^2 - R^2}$

$$Z^2 = R^2 + (X_C - X_L)^2$$

$$(X_C - X_L)^2 = Z^2 - R^2$$

$$X_C - X_L = \sqrt{Z^2 - R^2}$$

$$X_C = X_L + \sqrt{Z^2 - R^2}$$

39. 105 volts. First solve for the voltage across R_2.

$E = IR$

$E_{R2} = 2(15)$

$E_{R2} = 30$ volts.

Since R_3 is in parallel with R_2 it must also drop 30 volts. Thus, we can find the current through R_3:

$I = \dfrac{E}{R}$

$I = \dfrac{30}{30}$

I = 1 amp.

Now, the total current in the circuit is equal to the sum of the currents in the two parallel branches or 3 amps. This means that 3 amps of current is flowing through R_1. Therefore, R_1 drops (25 ohms × 3 amps) = 75 volts. Thus, the total applied voltage is 75 volts plus 30 volts equals 105 volts.

40. 95 volts. First find the current through R_4. $I = \dfrac{E}{R} = \dfrac{5}{5} = 1$ amp. Then find the voltage dropped by R_3. $E = IR = 1(20) = 20$ volts. Thus, the voltage across R_2 must be 5 volts + 20 volts = 25 volts. Consequently, the current through R_2 is: $I = E/R$; $I = 25/10 = 2.5$ amps. This means that the total current through R_1 is 1 amp + 2.5 amps = 3.5 amps. Now, find the voltage dropped across R_1: $E = IR$; $E = 3.5(20)$; $E = 70$ volts. Thus $E_T = 70$ volts + 25 volts = 95 volts.

41. $$\begin{array}{r} 3 + j6 \\ \underline{7 + j2} \\ 10 + j8 \end{array}$$

42. $$\begin{array}{r} 7 + j\,2 \\ \underline{9 - j17} \\ 16 - j15 \end{array}$$

43. $$\begin{array}{r} 9 - j4 \\ \underline{-3 + j5} \\ 6 + j1 \end{array}$$

44. $$\begin{array}{r} 8 + j3 \\ \underline{-4 - j7} \\ 4 - j4 \end{array}$$

45. $$\begin{array}{r} 17 - j6 \\ \underline{-11 + j8} \\ 6 + j2 \end{array}$$

46. $$\begin{array}{r} 3+j\ 7\\ 8-j13\\ 7+j\ 8\\ \hline 18+j\ 2 \end{array}$$

47. $$\begin{array}{r} 16-j13\\ -11+j\ 4\\ 5-j\ 2\\ \hline 10-j11 \end{array}$$

48. $$\begin{array}{r} 23+j14\\ -17-j26\\ 1-j\ 3\\ \hline 7-j15 \end{array}$$

49. $$\begin{array}{r} 2-j11\\ -19+j17\\ -\ 4-j\ 6\\ \hline -21\quad\ \ \end{array}$$

50. $$\begin{array}{r} -\ 6-j18\\ +12+j14\\ +\ 2+j21\\ \hline 8+j17 \end{array}$$

51. $$\begin{array}{l} 7+j\ 6\\ 3+j\ 2\\ \hline 21+j18\\ \quad\ +j14+j^2\,12\\ \hline 21+j32+j^2\,12 \end{array}$$

$$= 21 + j32 - 12 = 9 + j32$$

52. $$\begin{array}{l} 11+j\ 2\\ \ \ 2-j\ 7\\ \hline 22+j\ 4\\ \quad\ -j77-j^2\,14\\ \hline 22-j73-j^2\,14 \end{array}$$

$$= 22 - j73 + 14 = 36 - j73$$

53. $$\begin{array}{l} -2-j9\\ -3+j4\\ \hline +6+j27\\ \quad\ -j\ 8-j^2\,36\\ \hline +6+j19-j^2\,36 \end{array}$$

$$= +6 + j19 + 36 = 42 + j19$$

54. $$\begin{array}{l} \quad\ 8-j\ 7\\ \ -3+j\ 5\\ \hline -24+j21\\ \qquad\ +j40-j^2\,35\\ \hline -24+j61-j^2\,35 \end{array}$$

$$= -24 + j61 + 35 = 11 + j61$$

55. $$\begin{array}{l} 3+j2\\ 4+j6\\ \hline 12+j8\\ \quad\ +j18+j^2\,12\\ \hline 12+j26+j^2\,12 \end{array}$$

$$= 12 + j26 - 12 = j26$$

Now multiply j26 times 5 − j8

$$\begin{array}{l} \quad 5-j8\\ j\ 26\\ \hline j130-j^2\,208 \end{array}$$

$$= j130 + 208 = 208 + j130$$

56. $$\frac{30+j30}{4+j2} = \frac{30+j30\,(4-j2)}{(4+j2)\,(4-j2)}$$

$$= \frac{120+j120-j60-j^2\,60}{16-j^2\,4}$$

$$= \frac{180+j60}{20} = 9+j3$$

57. $$\frac{60 - j11}{5 - j6} = \frac{60 - j11\,(5 + j6)}{(5 - j6)\,(5 + j6)}$$

$$= \frac{300 + j305 - j^2 66}{25 - j^2 36} = \frac{366 + j305}{61}$$

$$= 6 + j5$$

58. $$\frac{69 + j17}{4 - j3} = \frac{69 + j17\,(4 + j3)}{(4 - j3)\,(4 + j3)}$$

$$= \frac{276 + j275 + j^2 51}{16 - j^2 9}$$

$$= \frac{225 + j275}{25} = \frac{25(9 + j11)}{25}$$

$$= 9 + j11$$

59. $$\frac{44 - j168}{7 - j9} = \frac{44 - j168\,(7 + j9)}{(7 - j9)\,(7 + j9)}$$

$$= \frac{308 - j780 - j^2 1512}{49 - j^2 81}$$

$$= \frac{1820 - j780}{130} = \frac{130\,(14 - j6)}{130}$$

$$= 14 - j6$$

60. $$\frac{255}{6 + j7} = \frac{255\,(6 - j7)}{(6 + j7)\,(6 - j7)}$$

$$= \frac{1530 - j1785}{36 + 49}$$

$$= \frac{1530 - j1785}{85} = \frac{85\,(18 - j21)}{85}$$

$$= 18 - j21$$

61. (4 + j2) ohms. There are two ways to work this problem. One method is to substitute the given impedance values into the formula for two impedances in parallel, $Z_T = \frac{Z_1 Z_2}{Z_1 + Z_2}$. Another method is to assume an applied voltage; solve for the current in each leg; solve for the total current; and finally solve for the total impedance. Although the latter method sounds involved, it is usually the easier of the two. The solution using the second method is given below. An applied voltage of 100 volts is assumed. You could have assumed any other voltage and arrived at the same answer.

$$I_1 = \frac{E}{Z}$$

$$I_1 = \frac{100}{3 + j4} = \frac{100\,(3 - j4)}{3 + j4\,(3 - j4)}$$

$$= \frac{100\,(3 - j4)}{9 - j^2 16} = \frac{100\,(3 - j4)}{25}$$

$$= 12 - j16$$

$$I_2 = \frac{E}{Z}$$

$$I_2 = \frac{100}{8 - j6} = \frac{100\,(8 + j6)}{(8 - j6)\,(8 + j6)}$$

$$= \frac{100\,(8 + j6)}{64 - j^2 36} = \frac{100\,(8 + j6)}{100}$$

$$= 8 + j6$$

$$I_T = I_1 + I_2$$

$= (12 - j16) + (8 + j6)$

$= 20 - j10$

$$Z = \frac{E}{I_T} = \frac{100}{20 - j10} = \frac{100}{10\,(2 - j1)}$$

$$= \frac{10}{2 - j1} = \frac{10\,(2 + j1)}{(2 - j1)\,(2 + j1)}$$

$$= \frac{10\,(2 + j1)}{5} = 4 + j2$$

62. 2 amps. First convert the impedance from j operator form to ohms.

$Z = \sqrt{R^2 + X^2}$

$Z = \sqrt{40^2 + 30^2}$

$Z = \sqrt{1600 + 900}$

$Z = \sqrt{2500}$

$Z = 50$ ohms

Now find the current.

$$I = \frac{E}{Z} = \frac{100}{50} = 2 \text{ amps}$$

63. $(40 - j25)$ ohms.

$$Z = R_1 + R_2 + R_3 - jX_{C1} - jX_{C2} + jX_{L1} + jX_{L2}$$

$$Z = 12 + 17 + 11 - j75 - j50 + j40 + j60$$

$Z = 40 - j125 + j100$

$Z = 40 - j25$

64. $(18 + j10)$ ohms.

$Z_T = Z_1 + Z_2 + Z_3 + Z_4 + Z_5$

$$Z_T = (1 + j6) + (3 - j2) + (4 - j7) + (3 + j14) + (7 - j1)$$

$Z_T = (18 + j10)$

65. $I_T = 25$ amps.

$EX_L = 250$ volts.

$EX_C = 250$ volts.

Series-resonant circuit. This is a series resonant circuit since $X_C = X_L$. This means that the 10 ohms of capacitive reactance is exactly canceled by the 10 ohms of inductive reactance. Therefore, the only opposition to current flow is the 4-ohm resistor. Thus, $I_T = \frac{E}{Z} = \frac{100}{4} =$ 25 amps. And $EX_L = I(X_L) = 25 \times 10 = 250$ volts. Also, $EX_C = I(X_C) = 25(10) = 250$ volts.

66. $(3.9 + j2)$ amps or approximately 4.4 amps.

$I_T = I_R + jI_C - jI_L$

$$I_R = \frac{E}{R} = \frac{117}{30} = 3.9 \text{ amps}$$

$$I_C = \frac{E}{X_C} - \frac{117}{39} = 3 \text{ amps}$$

$$I_L = \frac{E}{X_L} = \frac{117}{117} = 1 \text{ amp}$$

$I_T = 3.9 + j3 - j1$

$I_T = (3.9 + j2)$ amps

$$I_T = \sqrt{(3.9)^2 + (3 - 1)^2}$$

$$I_T = \sqrt{(3.9)^2 + (2)^2}$$

$$I_T = \sqrt{15.21 + 4}$$

$$I_T = \sqrt{19.21}$$

I_T = 4.4 amps

67. 3.33 ohms.

First assume an applied voltage. Any value will work but 48 volts is particularly convenient.

$$I_T = I_{R1} + I_{R2} + I_{R3} - jI_L$$

I_{R1} = 48/16 = 3 amps

I_{R2} = 48/16 = 3 amps

I_{R3} = 48/8 = 6 amps

I_L = 48/6 = 8 amps

$$I_T = (12 - j8)$$

$$Z = \frac{E}{I_T}$$

$$Z = \frac{48}{12 - j8} = \frac{48}{4\,(3 - j2)}$$

$$= \frac{12\,(3 + j2)}{(3 - j2)\,(3 + j2)}$$

$$= \frac{36 + J24}{13} = 2.77 + j1.84$$

$$= \sqrt{(2.77)^2 + (1.84)^2} = 3.33 \text{ ohms}$$

68. (8 – j6) amps or 10 amps.

$$I = \frac{E}{Z}$$

$$I = \frac{E}{R + jX_L - jX_C}$$

$$I = \frac{E}{R + j\,2\pi fL - j\,\frac{1}{2\pi fC}}$$

$$I = \frac{E}{12 + j\,(6.28)\,(120)\,(.1) - j\,\frac{.159}{120\,(.000\,02)}}$$

$$I = \frac{150}{12 + j75 - j66}$$

$$I = \frac{150}{12 + j9}$$

$$I = \frac{150}{3\,(4 + j3)} = \frac{50}{4 + j3}$$

$$I = \frac{50\,(4 - j3)}{(4 + j3)\,(4 - j3)}$$

$$= \frac{50\,(4 - j3)}{16 - j^2 9} = \frac{50\,(4 - j3)}{25}$$

$$I = 8 - j6$$

$$I = \sqrt{(8)^2 - (j6)^2}$$

I = 10 amps

69. 1 amp.

$$I_C = \frac{E_C}{X_C};\ E_C = E_L;\ E_L = I_L\,(X_L);$$

E_C = 40 volts

$$I_C = \frac{40}{40} = 1 \text{ amp}$$

70. 55 amps.

At resonance $X_L = X_C$ and the two cancel each other. Thus, the only opposition to current flow is the 2-ohm resistor. I = E/Z; I = 110/2; I = 55 amps.

71. 510 ohms.

$$Z_T = \frac{Z_1 \times Z_2}{Z_1 + Z_2}$$

$$Z1 = 0 - j100$$

$$Z2 = 20 + j100$$

$$Z_T = \frac{-j100\,(20 + j100)}{-j100 + (20 + j100)}$$

$$Z_T = \frac{-j2000 - j^2\,10{,}000}{20}$$

$$= \frac{10{,}000 - j2000}{20}$$

$$Z_T = 500 - j100$$

$$Z_T = \sqrt{500^2 + 100^2}$$

$$Z_T = \sqrt{260{,}000}$$

$$Z_T = 510\Omega$$

Lesson Questions

Be sure to number your Answer Sheet X202.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of lessons before new ones can reach you.

1. Add the following:
   (1) $(3a^2 + 2b^2 + 6c + 3d^2)$ plus $(2a^2 - b^2 + c^2 - 4d^2)$
   (2) $(ax^3 + bx^2y + cxy^2 + y^3)$ plus $2ax^3 + ax^2y + 6cxy^2 - 4y^3$.

2. Perform the following subtractions:
   (1) From $6a - 3b + 2c + d$ take $2a - 4b - c + 3d$
   (2) From $12ax^2 - 6by^2 - 4cz^2$ take $6ax^2 + 2by^2 - 5cz^2$

3. Multiply:
   (1) $(a^2 - b^2 + 3c)$ times $(a + b)$ (2) $(3x^2 + y)$ times $(3x^2 - y)$

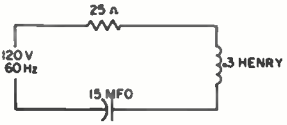
4. Divide:
   (1) $(4a^2 - 8ab + 4b^2) \div (2a-2b)$
   (2) $(18a^5 + 33a^4b + 6a^3b^2 - 11a^2b^3 + 20ab^4 + 32b^5) \div (3a + 4b)$

5. (1) Add $(4 + j17) + (3 - j2)$ (2) Subtract $(16 - j2) - (4 + j6)$

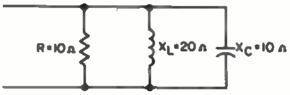
6. (1) Multiply $(6 + j9)(7 + j3)$ (2) Divide $(10 + j62) \div (8 + j2)$

7. If a resistance of 62 ohms is connected in series with a coil with a reactance of 42 ohms and a capacitor with a reactance of 100 ohms, what is the impedance of the circuit expressed in j-operator form?

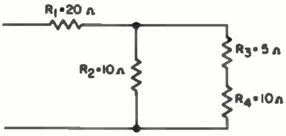
8. Find the current in the series circuit shown at the right. Give your answer in j-operator form.



9. Find the impedance of the circuit shown at the right. Give your answer in j-operator form.



10. Find the source voltage in the circuit shown at the right if the voltage across R_4 is 10 volts.



SUCCESS

The word "SUCCESS" means different things to different people. But the definition of "Success" which appeals to me most is this one, written by Mrs. A. J. Stanley.

"He has achieved success who has lived well, laughed often and loved much; who has gained the respect of intelligent men and the love of little children; who has filled his niche and accomplished his task; who has left the world better than he found it, whether by an improved poppy, a perfect poem, or a rescued soul; who has never lacked appreciation of earth's beauty or failed to express it; who has looked for the best in others and given the best he had; whose life was an inspiration; whose memory is a benediction."

Those of us who can even come close to achieving success of this kind will truly be contented, happy men.

John T. Thompson

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ACHIEVEMENT THROUGH ELECTRONICS

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MATHEMATICS IN PRACTICAL ELECTRONICS

REFERENCE TEXT X206

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MATHEMATICS IN PRACTICAL ELECTRONICS

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STUDY SCHEDULE

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This section explains why a knowledge of trigonometry is so valuable when working with complex electronic circuits.

☐ 2. Computing Shortcuts .... Pages 2 - 9

This important section will help you speed up and simplify many of your circuit calculations. It includes the rules for significant figures.

☐ 3. Trigonometry .... Pages 10 - 23

Here you study some of the basic fundamentals and principles of angles, radians, triangles, and trigonometric functions.

☐ 4. Coordinate Systems .... Pages 24 - 38

You study the rectangular and polar coordinate systems and learn how to convert from one system to the other.

☐ 5. Trigonometry in AC Circuits .... Pages 39 - 49

In this section you learn to use trigonometry to solve complex ac circuit problems.

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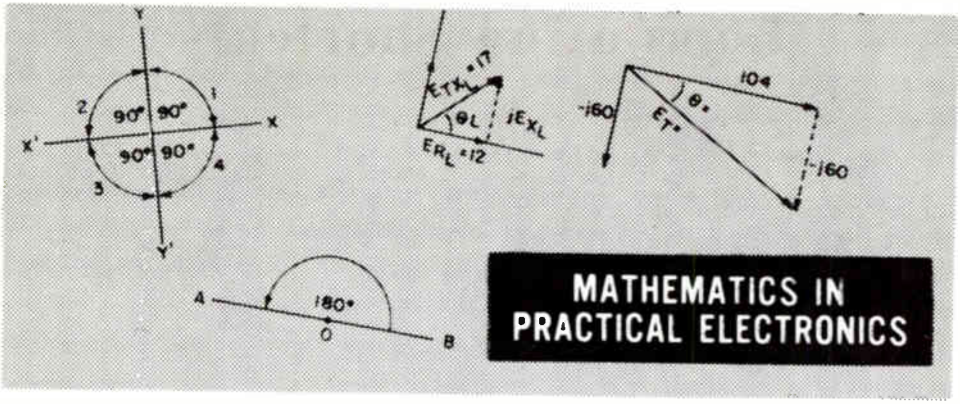


MATHEMATICS IN PRACTICAL ELECTRONICS

This text begins with a summary of shortcuts, some of which you have been using in your earlier lessons. Related to this summary is a discussion of significant figures. You will learn when it does not pay to be too exact and yet have reliable practical results.

You have learned many ways of dealing with the problems involved in making ac circuit computations. You know how to lay out the resultant vectors and measure the angles of lead or lag to determine their values. Although this is satisfactory for many problems and circuits, you will find it awkward when working with precision timing circuits, filter networks, and frequency control circuits that are so important in electronics work.

Many of these difficulties can be overcome by applying the principles of trigonometry to vector solutions. In this way we are able to account for the angles formed by vectors, as well as the length of the vectors, without having to rely on any construction or measurement. Although you may never have used trigonometry, or "trig" as it is usually called, it is a very valuable mathematical tool. It is not difficult to learn or use; in fact, it is simpler than many of the processes you have already learned.

By studying trigonometry, you will not only learn another method of computing with vectors, but you will also learn more about vector principles. You will see why a sine wave of alternating current is called a "sine wave" and learn why ac vectors are often called "phasors." In addition, you will learn to work with power in ac circuits and study some of the factors concerning the importance of "power factor." This knowledge of trigonometry will be of value to you throughout your career in electronics. For example, this knowledge of trigonometry is essential when working with computer equipment.

In this lesson you will also learn how to construct and use different types of graphs that will enable you to present complex information clearly and precisely. The importance of graphs cannot be overemphasized, because the technical texts and references which you will constantly need in your work use this form of presentation. In many ways, this is the most important lesson on mathematics since you will be using and reviewing all previous material and "polishing up" the rough edges.

Computing Shortcuts

Many simple calculations in electronics can become quite tedious because of the size of the numbers involved. Take the case of finding the plate current of a tube by measuring the voltage drop across the plate load resistor. Assuming there is a 7.0-volt drop across a 22,000-ohm resistor, what is the current? Ohm's Law tells us that we divide the voltage by the resistance to get the current. This is simple enough, but look at the arithmetic involved:

$$\begin{array}{r}
.00031818\\
22000\overline{)7.00000000}\\
\underline{6\,6000}\\
40000\\
\underline{22000}\\
180000\\
\underline{176000}\\
40000\\
\underline{22000}\\
180000\\
\underline{176000}\\
4000
\end{array}$$

There are five digits in the divisor, nine in the dividend, and eight in the quotient. No matter how many places there are in the quotient, there will still be a remainder with either four or five digits in it.

Practically speaking, a lot of needless work was done in performing this division. This operation could have been simpler. For one thing, the quotient was carried three decimal places too many. The second simplification is to get rid of those three zeros in the divisor. When these things are done, your division looks like this:

$$\begin{array}{r}
.31\\
22\overline{)7.00}\\
\underline{6\,6}\\
40\\
\underline{22}\\
18
\end{array}$$

Admittedly, the quotients obtained by these two divisions have their decimal points in different places. However, the method that was used to get rid of the three zeros in the second divisor also shows us how to shift the decimal point in the second quotient.

How to take the unnecessary work out of practical calculations will be the subject of this section of the lesson. There are two parts of this section: One is concerned with the number of digits that should be used in any arithmetic operation; the other is how to get rid of zeros whose only purpose is to locate the decimal point.

The rules that you will learn in this section are not only labor-saving tricks, they greatly reduce the possibility of mistakes. Everyone makes mistakes in arithmetic. The more marks you have to make on a piece of paper, the more likely you are to make a mistake. By using no more figures than are absolutely necessary, you can reduce the likelihood of an incorrect answer.

EXPONENTIAL NUMBERS

Many of the numbers used in science represent either very large or very small quantities. The field of electronics is no exception. In many cases, the majority of the digits in the numbers are zeros. These zeros serve only to locate the decimal point. They are necessary but very inconvenient to work with.

Mathematicians working in the different fields of science have developed another way of writing these numbers. The method is simply to express the number as the product of two factors. One factor, called the *digit factor*, contains the significant digits (this term is explained later in this section). The other factor, called the ***exponential factor***, is a whole numbered power of 10 which properly locates the decimal point. This method of writing large and small numbers is sometimes called the scientific method of expressing numbers.

As examples, let's use the resistance and current values in the sample division earlier in this section. The resistance was 22,000 ohms. Using the two-factor method, this number is expressed as 2.2×10^4. The current is .000318. This is written using exponential numbers: 3.18×10^{-4}. To show that these new figures are correct, we multiply them. 10^4 is 10,000; multiply this by 2.2 and we get 22,000. 10^{-4} is .0001; multiply this by 3.18 and we get .000318.

Conversion from one system to the other is very simple and involves only determining the correct power of 10. One rule tells the whole story: The power of 10 is given by the number of places the decimal point must be moved to obtain the digit factor. Moving the decimal point to the left gives a positive exponent; moving the decimal point to the right gives a negative exponent. For convenience, the digit factor is usually written with only one digit to the left of the decimal point.

Here are some examples: Convert 473,000 to exponential form. The decimal point in the digit factor will come between the 4 and the 7; this is five places to the left, giving an exponent of +5. The digit factor is then 4.73 and the exponential factor is 10^5. The complete expression is 4.73×10^5. Convert 6,720,000. The decimal point moves six places to the left, giving 6.72×10^6. Convert .000706. The decimal point moves to the right four places making the exponent −4. The complete expression is 7.06×10^{-4}. Convert .0000000123. The decimal point moves eight places to the right giving 1.23×10^{-8}.

Converting the number back is just as easy: Move the decimal point as many places as the power of 10 shown by the exponent. If the exponent is positive, move the decimal point to the right; if the exponent is negative, move the decimal point to the left. After this conversion, every place must be shown. If the decimal point is moved more places than are occupied by digits in the digit factor, fill in the blank places with zeros.

To convert 3.14×10^{-2}, we must move the decimal point to the left two places. There is only one place in the digit factor to the left of the decimal point so that we must add a zero to the left of the 3. This results in .0314. To convert 3.14×10^2, the decimal point must move two places to the right. This time there are digits in the digit factor for each place moved over and no zeros are added. 3.14×10^2 is equal to 314.

As simple as this system is for general use, it is even easier to make conversions in electronics. Many times it is not even necessary to count the number of decimal places. The method of giving the values of voltage and current, and of components has the digits all counted. You seldom see 1,500,000 ohms written out in full; instead, it is written 1.5M or 1.5 meg. Either way it means 1.5 million. One million is equal to 10^6, so as soon as you see the expression megohm, you know that the exponential factor is 10^6.

There are a number of other common methods of indicating size in the name of a unit. For instance, 1 kilohertz is 1000 or 10^3 Hertz; 1K ohm means 1 kilohm or 10^3 ohms. The prefix "kil" or "kilo" immediately tells you that the exponential factor is 10^3. Similarly, 1 milliampere is 1/1000 of an ampere; 1 millihenry is 1/1000 of a henry; 1 millivolt is 1/1000 of a volt, etc. 1/1000 is $1/10^3$ or 10^{-3}. The prefix "milli" is just another way of writing 10^{-3}. In the same way, "micro" means 1/1,000,000 or 10^{-6}. "Micro-micro" means one millionth of a millionth or 10^{-12}. Basic units such as volts, amperes, henrys, etc. have an exponential factor of 10^0 or 1.

Multiplication and Division. Exponential numbers are at their best for multiplication and division. It is in these operations that they save the most work. These operations are actually performed in two parts. The indicated operation is performed on the digit factors and then on the exponential factors. As an example, suppose a calculation called for multiplying .0022 X 670 X 3.14. Converting and grouping digits gives $(2.2 \times 6.70 \times 3.14) \times (10^{-3} \times 10^2 \times 10^0)$. First multiply the digit factors together and you get 46.2836. Next, multiply the exponential factors by adding the exponents algebraically; $-3 + 2 + 0 = -1$. Combining the two factors you get 46.2836×10^{-1}. This can be simplified by moving the decimal point in the digit factor one place to the left giving $4.62836 \times 10^1 \times 10^{-1}$. Now the two exponents cancel, leaving 4.62836 as the final answer.

Division is just as easy. For example, divide .0572 by .0026. Converting and grouping gives

$$(5.72 \div 2.6) \times (10^{-2} \div 10^{-3})$$
$$5.72 \div 2.6 = 2.2$$

The division of the exponential factor is performed by subtracting the exponent of the divisor (−3) from the exponent in the dividend (−2).

$$-2 - (-3) = -2 + 3 = 1$$

The complete quotient of this division is 2.2×10^1 or 22. The same basic procedures are followed for operations with combined multiplications and divisions. As an example, take

$$(22{,}000 \div 80) \times (.032 \div 308) \times 7$$

Fig. 1 shows how this is set up and solved.

Power and Roots. Raising a number to a power is a special form of multiplication; taking a root is a special form of division. As in multiplication and division, we must perform the indicated

$$\begin{aligned} 22000 &= 2.2 \times 10^4 \\ 80 &= 8.0 \times 10^1 \\ 032 &= 3.2 \times 10^{-2} \\ 308 &= 3.08 \times 10^2 \\ 7 &= 7 \times 10^0 \end{aligned}$$

$$\left(\frac{2.2}{8.0} \times \frac{3.2}{3.08} \times 7\right) \left(\frac{10^4}{10^1} \times \frac{10^{-2}}{10^2} \times 10^0\right)$$

$$= \frac{2.2 \times 3.2 \times 7}{8.0 \times 3.08} \times \frac{10^4 \times 10^{-2} \times 10^0}{10^1 \times 10^2}$$

$$= \frac{49.28}{24.64} \times \frac{10^2}{10^3} = 2 \times 10^{-1} = .2$$

Fig. 1. Solving combined multiplication-division problems using exponential numbers.

operation on the digit factor and treat the exponential factor separately. An exponential number is raised to a power by multiplying the exponents. You can see that this will give the correct answer by considering the following:

$$10 \times 10 = 10^2$$
$$10 \times 10 \times 10 = 10^3$$

and therefore

$$10^2 \times 10^2 \times 10^2 = (10^2)^3$$

But we know that

$$10^2 \times 10^2 \times 10^2 = 10^{2+2+2} = 10^6$$
$$(10^2)^3 = 10^{(2)(3)} = 10^6$$

Extracting the root is the reverse of raising to a power. A root of an exponential number is taken by dividing the exponent by the digit indicating the root, 2 for square root, 3 for cube root, etc. Suppose you want the square root of 10^6. Dividing the exponent 6 by 2 gives 10^3. We know that $10^3 \times 10^3 = 10^6$ which shows that dividing the exponent by the root gives the correct result.

We know from arithmetic that $6 \div 2$ is the same as $6 \times \frac{1}{2}$. Thus, $\sqrt{10^6}$ may be written as $(10^6)^{\frac{1}{2}}$. Fractional exponents indicate that roots must be taken. When this method of indicating the roots is used, square root is handled as the 1/2 power, cube root as the 1/3 power, and so on. The square root of 10^6 could be written as $10^{6/2}$. The square root of 10^3 would be written as $10^{3/2}$.

At the beginning of this section, you learned that the exponent of 10 in an exponential number must be a whole number. This can lead to a slight complication when taking roots. Consider taking the square of 8.1×10^3. We would write this as $\sqrt{8.1 \times 10^{3/2}}$. But our exponential number system does not allow fractional or decimal exponents. In order to extract the square root of 8.1×10^3, we must have an exponent divisible by 2. We get this by increasing or decreasing the exponent and moving the decimal point in the digit factor accordingly.

$$8.1 \times 10^3$$
$$= 81 \times 10^2$$
$$= .81 \times 10^4$$

The square root of 81×10^2 is 9×10; the square root of $.81 \times 10^4$ is $.9 \times 10^2$. Both of these roots convert to 90 in the decimal system. 8.1×10^3 converts to 8100, the square root of which is 90 and you can see that we have obtained the correct result. To extract the cube root, the exponent of 10 must be divisible by 3; the exponent for a fourth root must be divisible by 4, etc.

Addition and Subtraction. There is nothing to be gained by converting decimal numbers into exponential numbers for addition and subtraction. However, addition and subtraction may occur as part of a calculation when exponential numbers are used to simplify multiplication and division. When addition and subtraction are indicated, you must remember that you can only add and subtract exponential numbers having the same power of 10. The reason for this is simple. For example, 160 + 16 = 176. But we can write 160 as 1.6×10^2 and 16 as 1.6×10. If we simply add 1.6 + 1.6, we get 3.2 which is not the correct answer for 160 + 16 regardless of whether we multiply it by 10 or 10^2. If we first change the numbers so that we have the same power of 10, then we will get the correct answer. For example, $160 = 16.0 \times 10$, and $16 = 1.6 \times 10$. Then,

$$16 \times 10 + 1.6 \times 10 = 17.6 \times 10 = 176$$

As you can see, the use of exponential numbers greatly simplifies multiplication and division when working with large numbers having many zeros adjacent to the decimal point and on either side of it. Still greater simplification can be obtained when some of the digits in a number like 4.62836 can be dropped. This is possible when we are working with measured values. In most practical work, it is seldom necessary to use more than four digits in any factor. The rules for dropping digits from a number which has been obtained by a measurement are the next subject that we take up.

SIGNIFICANT FIGURES

When you took arithmetic in grade school, the teacher probably listed numbers like 67,530, 4156, 873, and told you to "round them off" to the nearest thousand or hundred or ten. You did this sort of thing for homework two or three nights and that was the end of it. The next and last time you did this was on a test. Well, that time wasn't wasted; studying significant figures is just learning when to round off and how much.

The term "significant" is used here to mean: "having a meaning." In working with significant figures, you retain only those figures which have meaning and drop all others by "rounding off." The use of significant figures applies only to numbers which are connected in some way with measurements.

The figures that you used when studying mathematics were considered exact. 1 was 1, and 2 was 2. Each digit meant exactly what is said; not almost or approximately, or a little more or less. This is not true of numbers that are obtained by measurement. There is always a certain amount of estimating or guesswork in taking any measurement. The first step in using significant figures is to properly record the results of the measurement. This means putting down meaningful figures in a manner that shows how exact the measurement is.

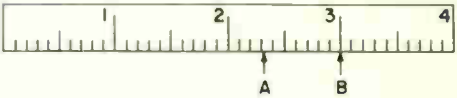


Fig. 2. Scale for showing use of significant figures in recording a measurement.

Fig. 2 shows a scale with two arrows at the bottom edge. The scale is used to show the position of pointers represented by the arrows. The scale is divided into four major units and each of these units is subdivided into ten parts. Suppose we want to read the position of arrow **A**. Arrow **A** lies between two and three units so the first figure is 2. Since the arrow is slightly past the third mark following the 2, the second figure is .3. Two figures are all that can be read directly from the scale marks. We estimate the third digit by mentally dividing the space between the scale marks into ten parts. Then we must decide which of these ten parts the arrow is nearest. 3 is the third digit for arrow **A**.

Perhaps you disagree with the reading of 2.33. Maybe you think the reading should be 2.32 or 2.34. Perhaps it should. The last digit is an estimate, not an exact figure. Because it is an estimate, different observers will record different values for this digit. However, if each observer reads the scale carefully, the readings should span only three digits; in this case, .02, .03, and .04. This is what you are saying when you record any measurement. Only the right-hand digit is an estimate and the error in reading is not more than ±1 in the right-hand figure.

Perhaps you think the arrow is exactly one-quarter of the way between 2.3 and 2.4; in other words, the reading should be 2.3 $\frac{1}{4}$. However, a mixed decimal and fraction is awkward to use. Since $\frac{1}{4}$ = .25, why not record the reading as 2.325? This, however, gives misleading information. To anyone using this figure, it means that you could tell the difference between 2.324, 2.325, and 2.326. Obviously you cannot, so 2.325 should not be recorded. You could, however, record 2.3 $\frac{1}{4}$. This indicates that you could tell the difference between 2.3, 2.3 $\frac{1}{4}$, and 2.3 $\frac{1}{2}$. It also says that no attempt was made to read the scale any closer than one-quarter of the smallest division. But instead of using a mixed decimal and fraction, it is better to estimate so that you will have only 3 digits.

The arrow B appears to be exactly on the "3" line. If it is recorded as 3, it indicates only that the reading is nearer to 3 than to 2 or 4. If it is recorded as 3.0, it means nearer to 3 than to 2.9 or 3.1. The correct way to record this is as 3.00. The two zeros to the right of the decimal point say that the scale can be read to 1/100 of a unit. 3.000 would be wrong because you cannot read the scale to thousandths. Even when a pointer falls directly on a scale mark, you cannot assume a more precise reading than at any other point on the scale.

Each of the readings, 2.33 and 3.00, has three digits. Therefore, we say that they have three significant figures. If we had read the scale only to the nearest scale mark, the readings would have been 2.3 and 3.0 with two significant figures each.

Zeros in a decimal number may or may not be significant, depending on where they are in the number. The decimal number .00678 has only three significant figures. The two zeros between the decimal point and the 6 are not considered significant.

.0067800 has five significant figures. The two zeros between the decimal point and the 6 are not significant, but the two zeros following the 8 are. If these last two digits had not been significant, they should not have been written; since they were written, you must assume that the measurement could be made to five figures.

Numbers like 22,000 create a problem. The "2's" are significant, but what about the zeros? As the number is written you cannot tell how many significant figures it has. Unless there is some note with the data, you must assume only two significant figures. However, if this were written as an exponential number, there would be no uncertainty. 2.2×10^4 has two significant figures. 2.20×10^4 has three significant figures. This is another advantage of exponential numbers; only significant figures appear in the digit factor.

Rules for Significant Figures. For convenience the rules for using significant figures will be listed by number. Then, examples of the application of the rules will be shown. In the examples, the rules that apply will be shown by number.

1. Only one uncertain figure should be recorded in giving the numerical value of any measured quantity. The uncertainty of the last figure will be ±1 unless otherwise stated.
2. When adding and subtracting with significant figures, keep only as many

decimals as are given in the number having the fewest decimals.

3. When multiplying and dividing, retain enough figures in each factor so that no factor has a greater uncertainty than the factor with the least number of significant digits.

4. When dropping nonsignificant digits by rounding off, increase the most right-hand retained figure by 1, if the figure to its right is 5 or greater.

5. Products and quotients should be rounded off so that the uncertainty is the same as that of the factor with the least number of significant figures.

Now some examples: Add 14.16 + .0078 + 1.234. The least number of decimal places is 2, so the last two numbers must be rounded off to two decimal places (Rule 2). .0078 becomes .01, and 1.234 becomes 1.23 (Rule 4). The sum is 15.40 (not 15.4). Since there are two decimal places in the numbers added, there must be two decimal places in their sum. (Common sense.)

Multiply 14.16 X .0078 X 1.234. The decimal number .0078 has the least number of significant figures (two), and an uncertainty of one part in 78. The other two factors must be rounded off. 14.16 rounded off to three figures becomes 14.2 (Rule 4) with an uncertainty of one part in 142. Rounded off to two figures it becomes 14 with an uncertainty of one part in 14. This uncertainty is much greater than one part in 78, so three significant figures must be used (Rule 3). 1.234 rounds off to 1.23 with an uncertainty of one part in 123. The product of 14.2 X .0078 is .11076; we round this off to .111 (Rule 5, Rule 4). .111 X 1.23 = .13653 which when rounded off becomes .137 (Rule 5, Rule 4).

What effect does this rounding off have on the accuracy of the calculation? None. If we had not rounded off any of the figures, the final product would have been .136292832. If we had not rounded off .11076, the final answer would have been .1362348. Both of these numbers round off to .136. Our answer was .137, just one unit greater. Since the last digit has an uncertainty of ±1, we can say the three answers were practically identical. By rounding off we have saved a lot of needless work without any loss of accuracy.

Multiply 19.7 X 9.81. Both numbers have the same number of significant figures. However, the larger number can be rounded without loss of accuracy. 19.7 has an uncertainty of one part in 197 or about .5%. 9.81 has an uncertainty of one part in 981 or about 1/10%. Rounding off 9.81 gives 9.8 with an uncertainty of one part in 98 or about 1%. This is much closer to the uncertainty of 19.7. The product without rounding off is 193.257; if 9.81 is rounded off to 9.8, the product is 193.06. Rounded to three figures, the answers are the same. It is apparent that Rule 4 can be modified at times to say that the percentage uncertainty of two factors should be nearly the same. It is hard to state this as a fixed rule and give exact values of how much the uncertainties can differ, but it does show how the use of common sense fits in with significant figures.

It is seldom necessary to use more than three significant figures in electronics. Except for precision parts, tolerances range from ±1% to ±20%; a good service meter has an accuracy of ±2% for voltage and current and ±5% for resistance. Keep the accuracy of your instruments and the tolerances of your parts in mind when performing calculations. Do not carry a lot of meaningless digits. Three significant figures are accurate enough for all but the most exacting laboratory work. Two significant digits are enough when using ±20% parts.

SELF-TEST QUESTIONS

1. Express the following in exponential form:
   - (a) 1,100,000
   - (b) 7200
   - (c) 0.00015
   - (d) 0.64
2. Convert the following exponential numbers to standard form:
   - (a) 326×10^{-12}
   - (b) 1.22×10^{6}
   - (c) 7.7×10^{-4}
   - (d) 9×10^{0}
3. Perform the following division and give the answer to three significant figures.

$$\frac{1}{6.28 \times 1550 \times 10^{3} \times 452 \times 10^{-7}}$$

4. Divide:

   $.0058 \times .000983$ by $.0000071$

5. Applying the rules for significant figures, add the following numbers:

$$\begin{array}{l} 7.92 \\ 3.0094 \\ 6.101 \\ \underline{0.0076} \end{array}$$

Trigonometry

Trigonometry is the study of the mathematical relationships that exist between the sides and angles of triangles. The word trigonometry itself is derived from two Greek words which mean the measurement of angles. The origin and earliest uses of trigonometry were for measuring distances and objects by using triangles. Today surveyors and construction engineers use trigonometry for this same purpose. However, the science of trigonometry has been developed to such a point that it is now commonly used for many other purposes.

As an electronics technician your most important use for trigonometry will be in the solution of the triangles formed by vector diagrams to determine phase relationships. Before you can actually learn to use trigonometry in this way, you must first learn some of the basic fundamentals and principles of angles, triangles, and coordinate systems.

ANGLES

When two straight lines meet at a point, an angle is formed. Thus, when the two lines OX and OY meet at the point 0 as shown in Fig. 3A, an angle is formed between the two lines. Similarly, the two lines OA and OB meeting at the point 0 in Fig. 3B also form an angle. The point 0, where the lines meet, is called the ***vertex*** of the angle, and the lines themselves are known as the sides of the angle. The angle in Fig. 3A is called "angle XOY" to show that it is the angle formed by lines OX and OY. Likewise, the angle in Fig. 3B is "angle AOB."

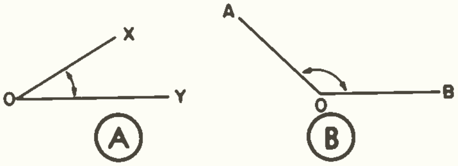


Fig. 3. Angles are formed when two straight lines meet.

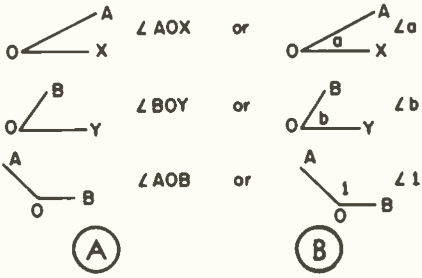


Fig. 4. Naming angles.

To save time and space, the symbol "$\angle$" is used in mathematics to represent the word "angle." Thus, the angles in Fig. 4A could be designated as $\angle$ AOX, $\angle$ BOY, and $\angle$ AOB. In working with a large number of angles, it is often awkward to describe angles in this way. Instead, we insert a letter or a number in the vertex of the angles, as shown in Fig. 4B and simply call them "$\angle$ a", "$\angle$ b", or "$\angle$ 1" as shown. Many times special designations are used to describe angles. For example, we often use the Greek letter theta, θ, in electronics to designate the phase angle. This would be written $\angle \theta$, and if we are working with several different phase angles we would indicate them with appropriate subscripts such as $\angle \theta_2$, $\angle \theta_3$, or perhaps $\angle \theta_a$ and $\angle \theta_b$.

The size or the magnitude of an angle is a measure of the space or distance between the sides and is determined by the difference in ***direction*** of the sides. Notice that it is only the difference in direction of the two sides that determines the size of an angle. The lengths of the sides do not in any way affect the size of the angle itself. You can easily see that either shortening or lengthening the sides of the angles shown in the figures will not change the size of the angles.

In working with the size or measurement of angles, as in measuring anything else, some standard unit of measurement must be chosen. Although it is easy to see that an angle is either smaller or larger or nearly the same size as another angle, this is not enough definition for the precision required in mathematics or electronics. Although there are three generally accepted units of measurements for angles, we will be concerned with only two of them: the degree (°), and the radian. To understand these two units of measurement, let's examine angles more closely, especially their relationship to circular measure.

An angle should be thought of as being generated by a line that starts at a certain initial position and rotates about the vertex of the angle until it stops at its final position. This is shown in Fig. 5. Consider the two straight lines: the short, heavy line OX and the lighter, longer line OY.

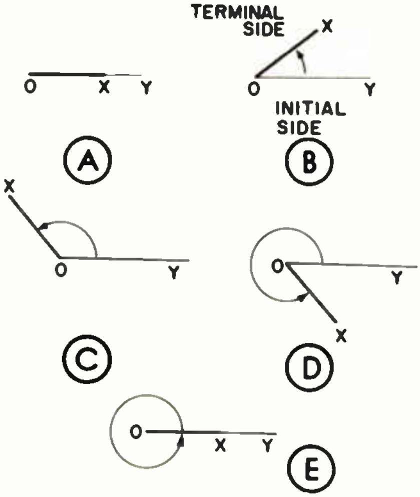


Fig. 5. Generation of angles.

In Fig. 5A, line OX is drawn on top of line OY and no angle is formed. However, in Fig. 5B, an angle is formed because the line OX is rotated counterclockwise from its initial position on line OY. Thus, the various angles XOY in Figs. 5B, 5C, and 5D are formed by the rotation of line OX from its initial position. The side of the angle that represents the original or initial position of the rotating side is known as the ***initial side***. The final position of the rotating side determines the size of the angle and is known as the ***terminal side***.

If the terminal side of the angle is rotated one complete revolution before it is stopped, the two lines are back at their original position, as shown in Fig. 5E. Thus, an angle is said to be formed by a line rotating about a point from one position to another. The unit of measure called the degree is based upon this formation by rotation. By definition, there are 360° in one complete revolution or 1° equals 1/360 of a complete revolution.

As we progress with our study of angles, triangles, and trigonometry, we will find that the degree is often a large unit of measurement. For this reason, the degree can be divided into smaller units called ***minutes***, written (′), and the minute can be further divided into units called ***seconds*** written (″). There are 60 minutes in one degree, and 60 seconds in each minute. Thus, the size of a certain angle might be written as 35° 46′ 57″ to tell us that the angle is 46 minutes and 57 seconds more than 35/360 of a revolution of the terminal side. Although these minutes and seconds may seem to be ridicuously small units, we will soon see that they can be very important. Remember, there are 360° in one revolution; 60 minutes in each degree (360 X 60 or 21,600 minutes in a revolution); and 60 seconds in each minute (60 X 60 or 3600 seconds in a degree and 60 X 60 X 360 or 1,296,000 seconds in a revolution).

In trigonometry, we often use the decimal system instead of minutes and seconds. For example, instead of saying that an angle is 36° 30′, we can write it as 36.5° because 30′ is half of 60′ and 1/2 equals .5. When using decimals, however, we must remember that there are 60 parts to a degree. For example, 36.25° is 36-1/4° which is 36 and 1/4 of 60, or 36° and 15′. Likewise, in converting 36° 12′ to decimals, we have 36-12/60° = 36-1/5° = 36.2°. It is very easy to make errors in converting from decimals to minutes or seconds.

Let's again use Fig. 5 to examine the other unit of angular measure: the radian. As the line OX rotates about the vertex to form the various angles, it must pass through every possible position from an angle of 0° (or no angle at all, as shown in Fig. 5A) to an angle of 360° (or one complete revolution, as shown in Fig. 5E). If we assume that the line OX never changes in length as it is rotating through this one revolution and place a pencil at the point X, we would find that a complete circle is drawn, as shown in Fig. 6.

Thus, we can say that since there are 360° in one revolution of side OX there are 360° in the circle. Also, since the *length* of OX has no bearing on the number of degrees in the revolution or in the size of the angles that could be formed by any one partial revolution, we can say that there are 360° in every circle, no matter how small or large it may be. Changing the length of OX would change the radius of the circle and its area, but not the number of degrees in it.

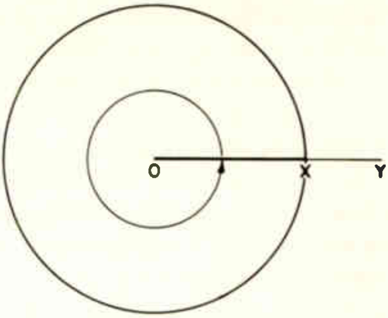


Fig. 6. Point X describes a complete circle in one complete revolution of terminal side OX.

If we were to mark off each degree on the circumference of the circle shown in Fig. 6, the degree marks would be very close together. In fact, they would be so close together that it might be difficult to show any space between them at all. In such a small circle, the difference between a degree or two would be insignificant as far as the linear distance between the marks is concerned.

However, suppose that we were considering a circle as large as the earth. At the equator, where it is about 25,000 miles around the earth, there would be nearly 70 miles between the degree marks and each degree would be extremely important. In fact, even a difference of a minute (1/60°) would be nearly 1.2 miles. Thus, a degree can be a very small unit or a very large unit, depending on where and how it is used. Consequently, the minute and second subdivisions can be quite important.

Although we don't often stop to realize it, a straight line is really a 180° angle and is therefore the most common angle. We can show that there are 180° in any straight line by rotating the terminal

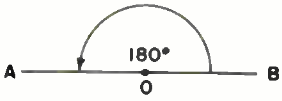


Fig. 7. Straight line is 180° angle.

side OA of any angle such as ∠ AOB in Fig. 7 until the line AB is straight. When the line AB is a straight line, the ∠ AOB equals one half a revolution of the rotating side, which is 180°.

Even though the straight line is the most common angle, the right angle is the most important. We are already familiar with the fact that there are 90° in a right angle and that there is a system of angular measurement based on right angles. The Pythagorean relationships of angles in a triangle having a right angle make it easy to solve electronics problems using trigonometry.

When two straight lines intersect each other so that four right angles are formed, the lines are said to be perpendicular to each other or mutually perpendicular. In Fig. 8, the two lines X′X and Y′Y are mutually perpendicular because angles 1, 2, 3, and 4 are all equal to 90° and are right angles. This is, of course, the basis of our coordinate systems which are used in making graphs, surveying, navigating, etc. We will learn more about this a little later.

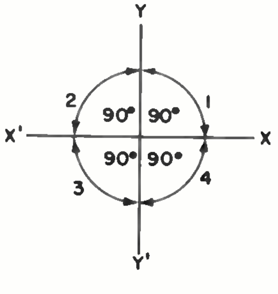


Fig. 8. Right angles formed when two lines are mutually perpendicular.

Any angle that is less than 90° is called an acute angle and any angle larger than 90° is called an obtuse angle. Two acute angles whose sum is equal to a right angle or 90° are called complementary angles. Either one of such acute angles may be called the complement of the other. Two angles whose sum is two right angles (180° or a straight line) are called supplementary angles.

Angles, of course, may be added, subtracted, multiplied, or divided, using the rules of arithmetic or algebra. We even have positive and negative angles to consider sometimes. A positive angle is generated when the terminal side is rotated counterclockwise to form the angle. If the angle is formed by the terminal side rotating clockwise it is called a negative angle.

RADIANS

The radian is a unit of measure that is based upon the length of an "arc" of a circle as compared with the radius of the circle. An "arc" is simply a part or section of the curved line that forms the circumference of a circle. An arc can be any length, but it must be a section of a true circle in order to be called an arc. Otherwise it would simply be called a curved line, or curve. An arc that is exactly equal in length to the radius of the circle of which the arc is a part is said to be a radian. A more formal way of saying it is that a radian is an angle that, when placed with its vertex at the center of a circle, intercepts an arc equal in length to the radius of the circle. Thus, if the ∠ XOY in the circle shown in Fig. 9A is to be equal to one radian, the length of the arc XY measured along the circumference of the circle must be equal to the

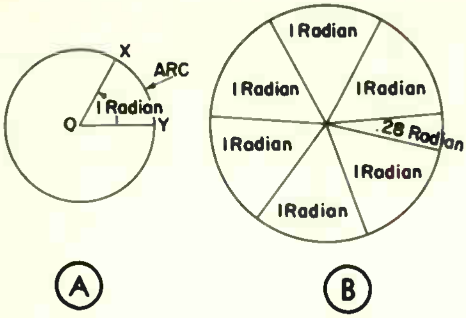


Fig. 9. Radian measure.

radius of the circle or the sides OX or OY of the angle.

If we lay out and mark off a circle using angles that are each equal to 1 radian, as shown in Fig. 9B, we will find that there are 6.28 radians in a circle. This must hold true for any circle regardless of its size since the length of arc intercepted by an angle of 1 radian must change directly as the radius of the circle changes. We are already familiar with the Greek letter π which we use in working with the area of circles. We know that it is a constant equal to 3.14. Therefore, we usually say that there are 2π radians in every circle since $6.28 \div 3.14 = 2$.

Many times you will want to change from radian measure to degrees, etc. Therefore, you should know how many degrees there are in a radian and how to convert from one to the other. Since there are 360° in every circle and 2π radians in every circle, 2π radians = 360°. From this:

$$\begin{aligned} 2\pi \text{ radians} &= 360^\circ \\ \pi \text{ radians} &= 180^\circ \\ 1 \text{ radian} &= 180/\pi \\ &= 57.32/57.3^\circ \end{aligned}$$

or approximately 57.3°. Accordingly, to change radians to degrees we would multiply the number of radians indicated by 57.3. Since 57.3 or $180/\pi$ is the multiplier when changing radians to degrees we would multiply the number of degrees by $\pi/180$ or .01745 in order to change them to radians.

Now let's consider triangles.

TRIANGLES

A triangle is a three-sided, closed plane figure. It is probably quite obvious what we mean by a closed, three-sided figure. However, if you have not studied geometry you may wonder what we mean by a

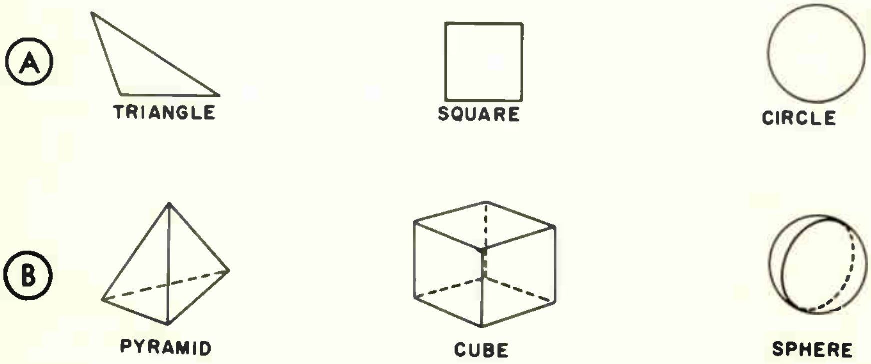


Fig. 10. (A) Plane figures. (B) Solid figures.

"plane" figure. A plane figure is simply a figure that has height and width, but no depth. Thus, a triangle, a square, a circle, or any other figure that is drawn flat on a piece of paper is a plane figure. A pyramid, a cube, or a sphere are all what we call "solid" figures, whether they actually exist or whether they are drawn with their depth indicated. Thus, the figures in Fig. 10A are plane figures and those in Fig. 10B are solid figures. The study of trigonometry includes both plane and solid figures, but in your work you will only need to be familiar with trigonometry for plane figures unless you enter some very specialized field work.

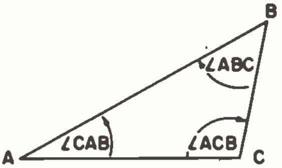


Fig. 11. A triangle has three angles and three sides.

Since a triangle has three sides, it must also contain three angles, as shown in Fig. 11. A triangle is named for reference purposes by naming the three vertexes of the three angles in order around the triangle. Thus, the triangle in Fig. 11 would be called triangle ABC. It might also be called triangle CBA, triangle BCA, triangle CAB, triangle BAC, or triangle ACB, depending on which vertex we start with and in which direction we go around. The mathematical symbol for a triangle is "Δ." Thus, the triangle in Fig. 11 could be written ΔABC.

The sum of the three angles in a triangle is always 180°. It can never be any more or any less no matter how large or small the triangle may be. This is very important in your work in trigonometry since you can always find the value of the third angle of any triangle if you know the other two.

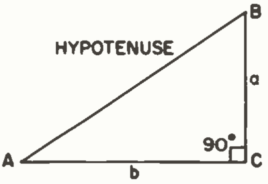


Fig. 12. A right triangle contains one right angle.

If one of the angles of a triangle is a right angle, the triangle is called a ***right triangle***. Accordingly, since a right triangle always has one 90° angle, the other two angles must be acute angles whose sum is also 90°. This relationship allows us to find one acute angle of a right triangle if we know the other acute angle. A right triangle is shown in Fig. 12. The fact that it is a right triangle is shown by drawing a small square at the vertex. The side of a right triangle that is opposite the right angle has been given the special name ***hypotenuse***. When a right triangle is in standard position as shown in Fig. 12, side a is called the ***altitude*** and side b the ***base***.

Two triangles are said to be ***similar*** when their corresponding angles are equal. In other words, similar triangles are triangles that are identical in shape, but not necessarily in size. Thus, although the corresponding angles of similar triangles are equal, the sides are not equal. However, there is a special relationship between the sides of similar triangles that forms the basis of trigonometry.

The corresponding sides of similar triangles are always proportional.

For example, the triangle in Fig. 13A is similar to the triangle in Fig. 13B,

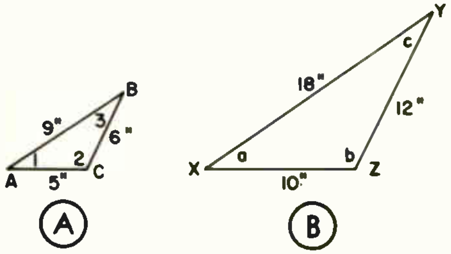


Fig. 13. Similar triangles have corresponding angles equal.

because ∠ 1 = ∠ a, ∠ 2 = ∠ b, and ∠ 3 = ∠ c. If we establish a ratio between any two sides of one of the similar triangles, we will find that it is equal to the ratio established between the corresponding sides of the other similar triangle. Thus, the ratio of side AC to side CB of ΔABC is:

$$\frac{AC}{CB} = \frac{5''}{6''}$$

The ratio of the corresponding sides of ΔXYZ would be:

$$\frac{XZ}{ZY} = \frac{10''}{12''} = \frac{5''}{6''}$$

Accordingly, we can establish a proportion from the two ratios as:

$$\frac{AC}{CB} = \frac{XZ}{ZY}$$

Also,

$$\frac{AB}{CB} = \frac{XY}{ZY} \text{ since } \frac{9''}{6''} = \frac{18''}{12''}$$

and

$$\frac{AC}{AB} = \frac{XZ}{XY} \text{ since } \frac{5''}{9''} = \frac{10''}{18''}$$

Remember that this proportionality between corresponding sides always exists when two or more triangles are similar.

Since we know that there are 180° in all triangles, we can determine if triangles are similar by knowing only two of the angles. If two angles of one triangle equal two angles of another triangle, the third angle must also be equal to each other and the triangles will be similar.

In the case of right triangles, the right angle of one is always equal to the right angle of another. Consequently, if one of the acute angles of one right triangle equals an acute angle of another right triangle, the two right triangles must be similar.

Suppose we have two similar right triangles such as the ones shown in Fig. 14. In these triangles, angle 1 and angle a are both equal to 30°. Any other right triangle that has one of its acute angles equal to 30° will be similar to these right triangles. If we examine the ratios of any two sides of these similar right triangles, we will discover a very important fact.

The ratio of the side opposite the 30° angle to the hypotenuse of any right triangle containing a 30° angle is always equal to .5. For example, the ratio of the side opposite the 30° angle, BC, to the

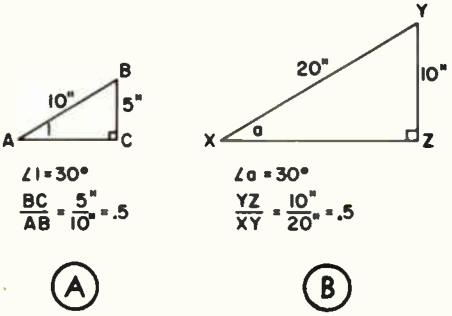


Fig. 14. Right triangles are similar if one acute angle equals the corresponding acute angle.

hypotenuse, AB, of ΔABC in Fig. 14 is equal to:

$$\frac{BC}{AB} = \frac{5''}{10''} = .5$$

Likewise, the same ratio exists for the corresponding sides of ΔXYZ because:

$$\frac{YZ}{XY} = \frac{10''}{20''} = .5$$

Since any other right triangle containing an acute angle of 30° must be similar to these, the ratio of the side opposite the 30° angle to the hypotenuse must always be equal to .5 for any right triangle that contains a 30° angle. Mathematically, this can be written as:

$$\frac{\text{side opp } 30^\circ}{\text{hypotenuse}} = .5$$

By applying this equation, we can determine any one of the factors if one of the others is known.

If we have a right triangle where one side equals 12.5 and the hypotenuse equals 25, we can tell that the angle opposite the 12.5 side must be equal to 30° whether it is given to us or not. If one of the acute angles is 30°, the other must be 60° because $30^\circ + 60^\circ + 90^\circ = 180^\circ$. Or, if we know that the hypotenuse of a right triangle equals 50 and one of the angles equals 60°, we can find the value of one of the sides because:

$$180^\circ - 90^\circ - 60^\circ = 30^\circ$$

and

$$\frac{\text{side opp } 30^\circ}{\text{hypotenuse}} = .5$$

and

$$\frac{\text{side opp } 30^\circ}{50} = .5$$

and

$$\text{side opp } 30^\circ = 25$$

Now, if we were to construct a right triangle containing a 29° angle and compute the same ratio for it, we would find that it would equal .4848. Thus, any time a ratio of the side opposite the angle to the hypotenuse works out to .4848, we know that the angle would be 29° because the ratios of corresponding sides of similar triangles are always equal. By continuing in this way we could work out the ratios for all possible angles that can exist in a right triangle and use these ratios to compute other unknown facts about their triangles.

This is trigonometry in its most basic form. Mathematicians have worked out ratios for all the angles it is possible to have in a right triangle and listed them in tables. These ratios are called the ***trigonometric functions*** of angles and can be used for computing unknown facts about similar right triangles. Since the functions are computed for all the angles that can exist, any right triangle you may work with will be similar to one for which the functions are listed.

TRIGONOMETRIC FUNCTIONS

We have seen that certain ratios can be established between two of the sides of a right triangle and that these same ratios will exist between the corresponding sides of any similar right triangle, no matter how large or how small it may be. These ratios are called the trigonometric functions of the angles to which they are related. If you examine any right triangle carefully, you will see that there are six of these ratios or "functions" that can be established for each of the acute angles of the triangle. These six functions have been given special names that you must learn and thoroughly understand in order to make any practical use of trigonometry.

Let's look at the typical right triangle shown in Fig. 15 and consider the angle θ at the lower left. Notice that the three sides of this right triangle have been given special names.

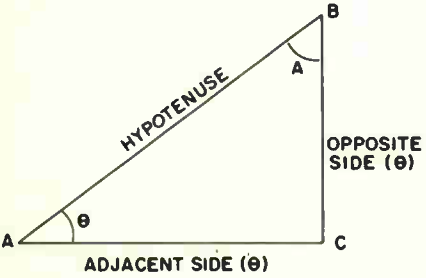


Fig. 15. Right triangle showing names of sides with respect to $\angle\theta$.

The side, BC, opposite the angle θ is called the ***opposite side***. The side, AC, of angle θ is called the ***adjacent side***. The side, AB, opposite the right angle is called the ***hypotenuse***. The hypotenuse and the adjacent side form the angle θ. Using these special names, the six separate ratios or functions that can be established for the acute angle θ are:

1. $\frac{BC}{AB}$ or $\frac{\text{opposite side}}{\text{hypotenuse}}$ is the function called the ***sine*** of the angle θ.

2. $\frac{AC}{AB}$ or $\frac{\text{adjacent side}}{\text{hypotenuse}}$ is the function called the ***cosine*** of the angle θ.

3. $\frac{BC}{AC}$ or $\frac{\text{opposite side}}{\text{adjacent side}}$ is the function called the ***tangent*** of the angle θ.

4. $\frac{AC}{BC}$ or $\frac{\text{adjacent side}}{\text{opposite side}}$ is the function called the ***cotangent*** of the angle θ.

5. $\frac{AB}{AC}$ or $\frac{\text{hypotenuse}}{\text{adjacent side}}$ is the function called the ***secant*** of the angle θ.

6. $\frac{AB}{BC}$ or $\frac{\text{hypotenuse}}{\text{opposite side}}$ is the function called the ***cosecant*** of the angle θ.

The first three of these functions are the most commonly used in electronics. If you examine them carefully, you will see that the cotangent is simply the reciprocal of the tangent, the secant is the reciprocal of the cosine, and the cosecant is the reciprocal of the sine. Since all the sides of the triangle are taken into consideration in the first three functions (sine, cosine, and tangent), the reciprocal relationships expressed by the cotangent, secant, and cosecant do not tell us anything really new. They just express it in a different way to provide certain conveniences for persons who work extensively with trigonometry. Since you will probably not be using trigonometry enough to make it worthwhile, you do not have to memorize the last three functions. However, it is important that the first three functions be memorized.

These trigonometric functions are usually abbreviated as follows:

$$\sin\theta = \frac{\text{opp}}{\text{hyp}}$$

$$\cos\theta = \frac{\text{adj}}{\text{hyp}}$$

$$\tan\theta = \frac{\text{opp}}{\text{adj}}$$

$$\csc\theta = \frac{\text{hyp}}{\text{opp}}$$

$$\sec\theta = \frac{\text{hyp}}{\text{adj}}$$

$$\cot\theta = \frac{\text{adj}}{\text{opp}}$$

In addition to the angle θ in the triangle shown in Fig. 15, we also have another acute angle. This is ∠ A at the top of the triangle and it is the "complement" of the angle θ because ∠ θ + ∠ A must equal 90° in a right triangle. Angle A also has six separate ratios or functions which can be established between its sides. These six functions of angle A are stated just the same as those for ∠ θ. In other words:

$$\sin A = \frac{\text{opp}}{\text{hyp}}$$

$$\cos A = \frac{\text{adj}}{\text{hyp}}$$

$$\tan A = \frac{\text{opp}}{\text{adj}}, \text{etc.}$$

However, notice that the side *opposite* angle A is the side that was adjacent to angle θ. Likewise, the side adjacent to angle A is the side that was opposite angle θ. Thus, although the trigonometric functions of sin, cos, tan, etc., are stated the same for either of the acute angles, the sides actually referred to in these functions as "opposite" and "adjacent" are different.

For this reason, even though we can simply say:

$$\sin = \frac{\text{opp}}{\text{hyp}}$$

$$\cos = \frac{\text{adj}}{\text{hyp}}$$

$$\tan = \frac{\text{opp}}{\text{adj}}$$

as a general statement of the trigonometric functions, we must express the specific angle as:

$$\sin\theta = \frac{\text{opp}}{\text{hyp}}$$

or

$$\cos A = \frac{\text{adj}}{\text{hyp}}$$

in order for our expression to have any specific meaning for a particular triangle. In fact, as you can see from studying the sides and angles of Fig. 15

$$\sin\theta = \frac{\text{opp}}{\text{hyp}} = \frac{BC}{AB}$$

but BC is adjacent to angle A, so

$$\frac{BC}{AB} = \frac{\text{adj}}{\text{hyp}}$$

or the cosine of angle A. Thus,

$$\sin\theta = \frac{BC}{AB} = \cos A$$

and sin θ equals cos A.

The following relationships between the functions of one acute angle and its complement can be worked out by referring to Fig. 15.

Angle (θ)	Sides Used	Complement (A)
$\sin\theta$	$= \frac{\text{opp}}{\text{hyp}} = \frac{BC}{AB} = \frac{\text{adj}}{\text{hyp}} =$	$\cos A$
$\cos\theta$	$= \frac{\text{adj}}{\text{hyp}} = \frac{AC}{AB} = \frac{\text{opp}}{\text{hyp}} =$	$\sin A$
$\tan\theta$	$= \frac{\text{opp}}{\text{adj}} = \frac{BC}{AC} = \frac{\text{adj}}{\text{opp}} =$	$\cot A$
$\cot\theta$	$= \frac{\text{adj}}{\text{opp}} = \frac{AC}{BC} = \frac{\text{opp}}{\text{adj}} =$	$\tan A$
$\sec\theta$	$= \frac{\text{hyp}}{\text{adj}} = \frac{AB}{AC} = \frac{\text{hyp}}{\text{opp}} =$	$\csc A$
$\csc\theta$	$= \frac{\text{hyp}}{\text{opp}} = \frac{AB}{BC} = \frac{\text{hyp}}{\text{adj}} =$	$\sec A$

Tables of Functions. We mentioned earlier that mathematicians have worked out trigonometric functions or ratios of the sides of triangles for all possible angles and listed them in tables. They are called Tables of Functions. Some of them are very detailed, such as those used in navigation where the functions are listed in minutes and seconds for all the angles. This is necessary for this type of work because, as we have seen, even a few minutes can mean several miles when we are considering the whole earth.

However, such detailed tables require a thick book which would not be practical for most of your work in electronics. Usually, accuracy to one degree, or possibly a few tenths of a degree, will be close enough. A typical Table of Functions that is simple and efficient is shown in Fig. 16. This table lists the sine, tangent, cotangent and cosine for angles from 0° through 90° in a convenient form.

The angles from 0° to 45° are listed in steps of 1° in the column marked "Degrees" at the left of the table. In the next column, the sine of all the angles from 0° to 45° are listed, then the tangent, the cotangent, and the cosine of the angles in the indicated columns. You should be familiar enough with tables of this sort to find the indicated functions of the angles from 0° through 45° without any trouble. For example, to find any of the functions for an angle, say 36°, we read down the degree column until we come to 36. Then, reading to the right, the sine of 36° is .5878, the tangent is .7265, the cotangent is 1.3764, and the cosine is .8090.

We know that the sine of an angle is equal to the cosine of its complement. That is, in Fig. 15, the sine θ equals:

$$\frac{BC}{AB} = \cos A$$

Therefore, if the sine of 36° is equal to .5878, as shown in the table, this same value of .5878 must be equal to the cosine of 54° which is the complement of 36° (36° + 54° = 90°). Likewise, the cosine of 36°, which according to the table is .8090, must be equal to the sine of 54°. Thus, if we know the functions of the angles from 0° to 45°, we automatically know the functions of all the angles from 0° to 90° if we remember the relationships of the functions of complementary angles.

Most tables are made so that they can be read up as well as down, like the one in Fig. 16. Notice that the functions are

Degrees	Sine	Tangent	Cotangent	Cosine	
0	.0000	.0000	......	1.0000	90
1	.0175	.0175	57.290	.9998	89
2	.0349	.0349	28.636	.9994	88
3	.0523	.0524	19.081	.9986	87
4	.0698	.0699	14.301	.9976	86
5	.0872	.0875	11.430	.9962	85
6	.1045	.1051	9.5144	.9945	84
7	.1219	.1228	8.1443	.9925	83
8	.1392	.1405	7.1154	.9903	82
9	.1564	.1584	6.3138	.9877	81
10	.1736	.1763	5.6713	.9848	80
11	.1908	.1944	5.1446	.9816	79
12	.2079	.2126	4.7046	.9781	78
13	.2250	.2309	4.3315	.9744	77
14	.2419	.2493	4.0108	.9703	76
15	.2588	.2679	3.7321	.9659	75
16	.2756	.2867	3.4974	.9613	74
17	.2924	.3057	3.2709	.9563	73
18	.3090	.3249	3.0777	.9511	72
19	.3256	.3443	2.9042	.9455	71
20	.3420	.3640	2.7475	.9397	70
21	.3584	.3839	2.6051	.9336	69
22	.3746	.4040	2.4751	.9272	68
23	.3907	.4245	2.3559	.9205	67
24	.4067	.4452	2.2460	.9135	66
25	.4226	.4663	2.1445	.9063	65
26	.4384	.4877	2.0503	.8988	64
27	.4540	.5095	1.9626	.8910	63
28	.4695	.5317	1.8807	.8829	62
29	.4848	.5543	1.8040	.8746	61
30	.5000	.5774	1.7321	.8660	60
31	.5150	.6009	1.6643	.8572	59
32	.5299	.6249	1.6003	.8480	58
33	.5446	.6494	1.5399	.8387	57
34	.5592	.6745	1.4826	.8290	56
35	.5736	.7002	1.4281	.8192	55
36	.5878	.7265	1.3764	.8090	54
37	.6018	.7536	1.3270	.7986	53
38	.6157	.7831	1.2799	.7880	52
39	.6293	.8098	1.2349	.7771	51
40	.6428	.8391	1.1918	.7660	50
41	.6561	.8693	1.1504	.7547	49
42	.6691	.9004	1.1106	.7431	48
43	.6820	.9325	1.0724	.7314	47
44	.6947	.9657	1.0355	.7193	46
45	.7071	1.0000	1.0000	.7071	45
	Cosine	Cotangent	Tangent	Sine	Degrees

Fig. 16. Table of functions.

listed again at the bottom of the table, but in the reverse order. In addition, at the extreme right we have another heading marked "Degrees." This we read from the bottom, 45°, to the top, 90°, in conjunction with the function headings at the bottom. Thus, to find the cosine of 63°, we read up the right-hand degree column to 63, then across to the extreme left to the column which is marked "cosine" at the bottom. This shows us that cosine 63° is .4540; cotangent 63° is .5095; tangent 63° is 1.9626; and sine 63° is .8910.

Thus, sine 63° is .8910 which is the cosine of its complement 27°. By studying the table, you will notice some important relationships between the various functions. The sine of 0° is .0000, but the cosine is 1.0000, while the sine of 90° is 1.0000 and the cosine is .0000. Thus, the sines of angles start from 0° and .0000 and work up to a maximum of 1.0000 at 90°. The cosine works out exactly the opposite; it has a value of 1 at 0° and decreases until it is .0000 at 90°. The value of the sine or the cosine of an angle can never be more than 1. The tangent also starts at 0° and .0000, but the tangent functions have no upper limit. At 89° it is 57.290, but as you can see, it is increasing in value rapidly as it approaches this upper limit. From 89° it increases to some infinite (unmeasurable) value at 90°.

Interpolation. Although accuracy to one degree is usually satisfactory, you may want to be accurate to a fraction of a degree. You can get this additional accuracy from the Table of Functions even though it shows only whole degree steps. We do this by a process known as interpolation. Suppose we want to find the sine of an angle of 36.5°. Since it is between 36° and 37°, we know that its sine must be more than the sine of 36° and less than the sine of 37°. Therefore, we look up the sine of both 36° and 37° and proceed as follows:

First, we subtract to find the difference between the values of the sines of the two angles. Thus:

$$\begin{array}{r} \text{sine } 37^\circ = .6018 \\ -\ \text{sine } 36^\circ = .5878 \\ \hline \text{difference} \quad .0140 \end{array}$$

The angle that we are trying to find the sine for is 36.5°, which is an increase of .5° over 36°. Therefore the sine of 36.5° must be the sine of 36° plus .5 of the difference between 36° and 37°.

$$.5 \times .0140 = .00700$$

Then, .5878 (sine 36°) plus .007 equals .5948, which is the sine of 36.5°.

To make sure that we understand this, let's try another example. What is the sine of 28° 15′? First,

$$\begin{array}{r} \text{sine } 29^\circ = .4848 \\ -\ \text{sine } 28^\circ = .4695 \\ \hline \text{difference} \quad .0153 \end{array}$$

Now, 28° 15′ is 15/60 or .25 more than sine 28°. Therefore:

$$.25 \times .0153 = .003825$$

and

$$.4695 + .003825 = .473325$$

which is the sine of 28° 15′. To interpolate sine functions, find the difference between the functions of the next smaller and the next larger angle. Then, multiply this difference by the amount of increase and add the product to the function of the smaller angle. The same procedure is used to interpolate tangent functions.

Interpolation of cosine and cotangent functions starts the same: Find the difference between the next smaller and next larger functions and multiply this difference by the amount of increase. Now, since the values of cosine and cotangent become smaller as the angle becomes larger, you must ***subtract*** the product from the value of the function of the smaller angle.

You have learned to find the value of a function of an angle by interpolation when it lies between two angles. A similar process is used to find an angle when the value of a function does not appear in the table.

For example, suppose we want to find the angle θ whose tangent is .5978. The Table of Functions does not show a tangent for .5978. But the tangent of 31° is .6009 and the tangent of 30° is .5774. Therefore, the angle θ lies somewhere between 30° and 31° since its tangent lies between the tangents of 30° and 31°.

First find the difference of the tangent values:

$$\begin{array}{r} \tan 31^\circ = .6009 \\ -\ \tan 30^\circ = .5774 \\ \hline \text{difference} = .0235 \end{array}$$

Therefore, an increase of 1° between 30° and 31° makes an increase of .0235 in tangent value.

Next, subtract the tangent of the smaller angle (30°) from the tangent of angle θ:

$$\begin{array}{r} \tan \theta = .5978 \\ -\ \tan 30^\circ = .5774 \\ \hline \text{difference} = .0204 \end{array}$$

The tangent shows an increase of .0204 from the tangent of 30°, therefore the angle which lies between 30° and 31° is determined by the fraction:

$$\frac{.0204}{.0235}$$

or .868 when expressed as a decimal. The angle θ whose tangent is .5978 must be 30.868°. Working to the nearest one tenth of a degree will usually be accurate enough. Therefore angle θ is equal to 30.9°.

Interpolation applies to all functions and all angles not shown in a table of functions.

SELF-TEST QUESTIONS

6. Define trigonometry.
7. How many minutes are there in 13 degrees? How many seconds?
8. How many radians are there in 360°?
9. What is the difference between an acute angle and an obtuse angle?
10. One acute angle of a right triangle is 32°, what is the other acute angle?
11. List and define the six trigonometric functions.
12. Using the table in Fig. 16, find the following:

    (a) sin 13°
    (b) cos 46°
    (c) tan 19°
    (d) sin 57°

13. Find the following:

    (a) sin 3.2°
    (b) tan 51.6°
    (c) cos 19.5°
    (d) sin 16.8°

14. Find the angle:

(a) whose sin is .3584
(b) whose tan is 1.9626
(c) whose sin is .7771
(d) whose cos is .5592

15. Find the angle:

(a) whose sin is .8141
(b) whose tan is .6081
(c) whose sin is .1581
(d) whose cos is .6665

Coordinate Systems

We have become use to expressing a vector as a binominal term by using the j operator. Now that we have learned a little about trigonometry, we can also express a vector as a numerical value and an angle. For example, suppose we have the simple circuit shown in Fig. 17. The coil has an inductive reactance of 15 ohms and is in series with a 15-ohm resistance. Neglecting the resistance of the coil itself, what is the impedance and the phase angle of the circuit?

We already know two ways to solve such a problem. The first method is to construct a very accurate vector diagram using the resistive and reactive components and then measure the resultant impedance vector and the phase angle. Although this can be done for simple circuits, the drawings can become complex and difficult to work with if the circuits are the least bit complicated. However, the greatest disadvantage in this method is that the accuracy depends on drawing neatly and precisely. Since most of us are not draftsmen or artists, it may be difficult to make a completely accurate drawing to scale and this gives a large margin for error when using this method.

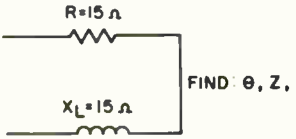
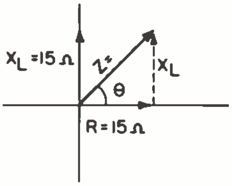


Fig. 17. Simple ac circuits.

The other method is to use the j operator and express the vector mathematically using a binomial number. This eliminates the need for many of the accurate diagrams because we can work with vectors mathematically to combine them into a final binomial representation of the resultant. Then, by using the Pythagorean Theorem, we can find the numerical value of the binomial representation which gives the length of the final vector. However, we still must construct a diagram and actually measure the angle of lead or lag to find the phase angle.

Using trigonometry to solve vector diagrams will eliminate the need for any construction or measurement in finding the phase angle as well as the impedance. It is also easier than finding the square roots of numbers as we do when using the Pythagorean Theorem. Now, let's use trigonometry to solve the circuit shown in Fig. 17.

The best way to begin is to lay out a simple sketch of the vectors involved. Since we are not going to make any



FIND θ, Z

$$\mathrm{TAN}\,\theta = \frac{\mathrm{Opp}}{\mathrm{Adj}} = \frac{X_L}{R} = \frac{15}{15} = 1.0000$$

$$\theta = 45^\circ$$

$$\mathrm{SIN}\,\theta = \frac{\mathrm{Opp}}{\mathrm{Hyp}} = \frac{X_L}{Z}$$

$$Z = \frac{X_L}{\mathrm{SIN}\,45^\circ} = \frac{15}{.7071} = 21.2\,\Omega$$

Fig. 18. Trigonometric solution to circuit in Fig. 17.

measurements, this can be a rough diagram as shown in Fig. 18. Here the resistance component becomes a vector that forms the base of a triangle. The reactance component becomes a vector that represents the altitude of a triangle. Since the phase angle between a pure resistance and a pure inductance is exactly 90°, these two vectors form a 90° angle. Therefore, the resultant impedance vector which we draw from the tail of the resistance vector to the head of the reactance vector becomes the hypotenuse of a right triangle. We want to know the value of the length of this impedance vector and the size of the phase angle θ that is formed by it.

Looking at this triangle in terms of what we know about it as compared to what we want to know, we see that we know the value of the side opposite the angle θ and the value of the side adjacent to the angle θ. Now, we consider the trigonometric functions that we have just learned to see which one of them fits the unknown angle θ in terms of the known values. If we go down the list of functions, the first one we come to that uses the opposite and adjacent sides is the tangent. This states that

$$\tan\theta = \frac{\text{opp}}{\text{adj}}$$

If we use this function as an equation, and substitute the known values, we have:

$$\tan\theta = \frac{\text{opp}}{\text{adj}} = \frac{X_L}{R} = \frac{15}{15} = 1.0000$$

This tells us that the tangent of the angle θ is equal to 1.0000 when the opposite side and the adjacent side are both equal to 15.

Now, we turn to the Table of Functions in Fig. 16 and look down the column headed "Tangent" until we come to 1.0000. Then, looking to the left, we find that this number is the tangent of an angle of 45°. Thus, the phase angle θ in our diagram must equal 45°, because our equation states that $\tan\theta = 1.0000$ and our Table of Functions shows us that only 45° has a tangent equal to 1.0000.

Now that we have found our phase angle, we will want to find the value of our impedance vector. We can do this quite easily now that we know the value of θ because:

$$\sin\theta = \frac{\text{opp}}{\text{hyp}} = \frac{X_L}{Z}$$

Stated in terms of Z, this becomes:

$$Z = \frac{X_L}{\sin\theta} = \frac{15}{\sin 45^\circ}$$

Then, from the Table of Functions,

$$\sin 45^\circ = .7071 \text{ and } Z = \frac{15}{.7071}$$

Performing the mathematics:

$$Z = 15 \div .7071 = 21.2$$

Thus, using two steps of simple algebra and arithmetic and the Table of Functions, we can find both the phase angle (45°) and the impedance (21.2Ω) for the circuit shown in Fig. 17. By using the trigonometric functions of angles in this way, we can find the value of either of the acute angles of a right triangle if two of the sides are known, or the value of the two unknown sides if one of the sides and an acute angle are known.

Thus, we can say that the impedance is $21.2 \underline{/+45^\circ}\Omega$. As you recall from an earlier lesson, the impedance can also be expressed as a binomial: $(15 + j15)\Omega$. That is, the impedance can be expressed as a number and an angle or as a binomial. Either expression gives us a number picture of the vector and allows us to construct an accurate diagram of both the resultant vector and its components. They also allow us to compute with the vectors mathematically.

These two methods of noting vectors mathematically are given special names. The first, using a binomial such as 15 + j15 ohms is termed a ***rectangular*** or ***Cartesian*** coordinate. The second, using a number and an angle such as $21.2 \underline{/+45^\circ}$ ohms is called a ***polar*** coordinate. Notice that in the polar form we give the angle a positive value to show that we are measuring it in a counterclockwise direction from the reference to vector Z.

We give the angle a negative sign when measuring clockwise from the reference to the vector Z. The angle is usually given the same sign as the corresponding j term when we use rectangular coordinates. Thus vector $Z = 20 + j20$ ohms would be written in polar form as $Z = 28.3 \underline{/+45^\circ}$ ohms.

Both of these methods of describing a vector or locating a point are commonly used. Measurements and computations are made either way, depending on the information desired. Often, when mechanical or electronic computers are used, conversions from rectangular coordinates to polar coordinates and back again are made constantly, depending on the nature of the information supplied, the type of information needed, and the equipment in the computer. Although we have actually learned nearly everything about these two systems of describing a vector, our work in electronics is such that we have used them constantly without knowing some of the basic concepts of these systems of coordinates. Now is a good time to catch up on some of these basic considerations.

RECTANGULAR COORDINATES

A coordinate system is simply a standard frame of reference for describing some particular value, condition, or place. Unless we have these standard references, even everyday occurrences would be difficult to explain or describe. For example, the common directions of north, south, east and west have no meaning unless we know what they are north, south, east or west from. Describing the voltage-current relationship of a circuit as 120 volts lagging a current of 1 ampere by 30° has no meaning unless we are familiar with a standard condition to compare it with. For this reason, standard reference frames have been established for universal use so that everyone will have the same means for describing a situation so that everyone else can understand it.

Originally, the rectangular coordinate system was devised for giving directions in a standard manner. Since this system is so simple and so widely understood, it

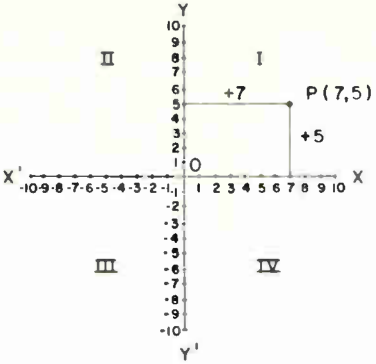


Fig. 19. Coordinate reference frame.

has been adopted for locating values and describing conditions throughout the fields of science and mathematics.

To begin with, let's call a rectangular coordinate system a device for associating points with pairs of numbers. The standard reference for this system consists of two mutually perpendicular lines, as shown in Fig. 19. One line is always horizontal and is labeled X′X as shown. Therefore, the other line labeled Y′Y is always vertical as shown, and the lines intersect at the point 0. We have used this device constantly in our work with vectors and it is nothing new except that we have never used these particular letters for the axes.

Now the two lines are called the coordinate axes and are said to be made up of the X axis (line X′X) and the Y axis (line Y′Y). The point 0 is called the origin. We can lay off scales along these axes to suit our particular purpose, but the scale from the origin, 0, to the right along the X axis is always positive, while the scale is always negative from the origin, 0, to the left along the X axis. Likewise, the scale from the origin, 0, up toward Y is always positive and the scale down from the origin, 0, to Y′ is always negative.

This reference frame consisting of the two coordinate axes serves as a means of locating any point in the plane of the axes by referring to two numbers. The two numbers completely express the position or distance of the point from the origin of the coordinate axes. For example, consider the point P in Fig. 19.

We can completely describe its position so that anyone familiar with this system can immediately locate it by saying it lies +5 from the X axis and +7 from the Y axis. The distance of the point from the Y axis, measured along the X axis is called the ***abscissa*** of the point. The distance of the point from the X axis measured by the scale on the Y axis is called the ***ordinate*** of the point. These two numbers, each with their proper algebraic sign, are called the ***coordinates*** of the point. In writing the coordinates of a point, the abscissa is written first and the ordinate second. Thus, we would write the coordinates of the point P in Fig. 19 as "the coordinates of P are (7, 5)."

The coordinate axes divide the area into four sections or quadrants as they are called. These quadrants are numbered in Fig. 19 by the Roman numerals I, II, III, IV. Notice that a point must have two positive coordinates to lie in the first quadrant and two negative coordinates to lie in the third quadrant. A point in the second quadrant must have a negative abscissa and a positive ordinate, while a point in the fourth quadrant has a positive abscissa and a negative ordinate.

This system of referring to a point by its coordinate is sometimes called the "Cartesian" coordinate system in honor of the French mathematician Descartes. It is also called the rectangular coordinate system because a rectangular figure is drawn when the points are completely located.

In electronics work, we use this standard coordinate reference frame constantly, but we usually use some other method of labeling the coordinate axes. However, regardless of the symbols we may use, the quadrant designations always remain the same, the signs of the scales are always the same, and we always consider the positive section of the X axis as the starting point or reference line. When the frame is assigned a degree system of reference, 0° is always at X, 90° at Y, 180° at X′, and 270° at Y′. Although most of our work will lie in the first and fourth quadrants, which is all we need to represent vectors consisting of coordinates using positive resistance, +jX and –jX, we will have some occasion to get into the second and third quadrants when we consider polyphase systems and "negative" resistances later in the course.

POLAR COORDINATES

As we have seen in studying ac circuits and trigonometry, degrees can be used to designate the points in the standard coordinate reference frame as shown in Fig. 20. Thus, we can locate a point P accurately and clearly by saying it is 10 units from the "0" of the graph and a line connecting the point "P" with "0" forms an angle of 45° with the positive X axis, as shown in Fig. 20. This would be written $10\underline{/+45^\circ}$ to show the length of a line from the origin, 0, to the point as 10 units; and the displacement of the line from 0° (measured counterclockwise) as $\underline{/+45^\circ}$. Thus, saying point P is $10\underline{/+45^\circ}$ would describe the location of the point in terms of polar coordinates. We call this the polar coordinate system because of its use in reference to the poles of the earth for navigation and surveying. Remember, a negative sign is used for angles generated or measured from 0° in a clockwise direction.

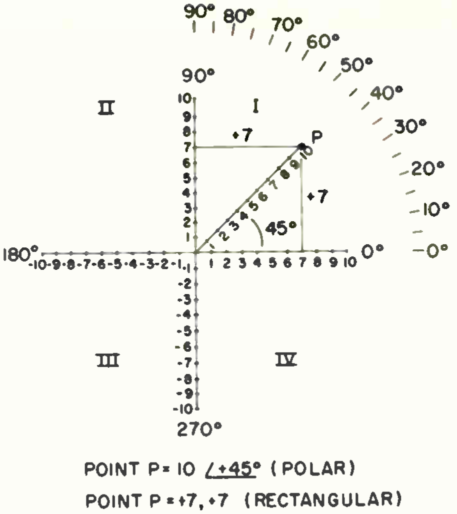


Fig. 20. Reference frame for polar coordinates.

CONVERTING POLAR AND RECTANGULAR COORDINATES

Point P in Fig. 20 can be completely described or located by using either polar coordinates or rectangular coordinates. Therefore, we may want to convert polar coordinates to rectangular coordinates and vice versa. This can easily be done by using the fundamentals of trigonometry.

For example, suppose we wish to refer to the point P in Fig. 21 in rectangular

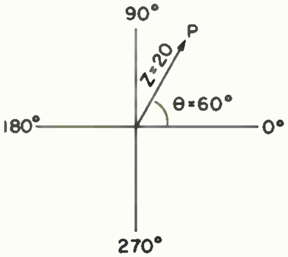


Fig. 21. Converting polar coordinates to rectangular coordinates.

coordinates so that it can be combined with other points that are also expressed as rectangular coordinates. When point P is expressed in polar form as an impedance vector and a phase angle it is written as $Z = 20\underline{/+60^\circ}$. To convert this impedance vector to its rectangular coordinates, we would express it as a resistance ± reactance.

The resistance component is always the adjacent side of $\angle\theta$ and the reactive component is always the opposite side of $\angle\theta$, representing the ±j term. Accordingly:

$$\cos\theta = \frac{\text{adj}}{\text{hyp}}$$

or

$$\text{adj} = \text{hyp} \times \cos\theta$$

Substituting:

$$R = Z\cos\theta$$

Likewise:

$$\sin\theta = \frac{\text{opp}}{\text{hyp}}$$

or

$$\text{opp} = \text{hyp} \times \sin\theta$$

Substituting:

$$X = Z\sin\theta$$

Then, since

$$Z = R \pm jX$$

we can substitute:

$$Z = Z\cos\theta \pm j(Z\sin\theta)$$

or

$$Z = Z(\cos\theta \pm j\sin\theta)$$

By applying this equation, we can convert polar coordinates to rectangular coordinates.

In Fig. 21, we would have:

$$Z = Z(\cos\theta \pm j\sin\theta)$$

Substituting:

$$Z = 20(\cos 60 + j\sin 60)$$

From our table:

$$Z = 20(.5 + j.866)$$

and:

$$Z = 10 + j17.32$$

would express

$$Z = 20\underline{/+60^\circ}$$

in rectangular coordinates.

For example, to convert the rectangular coordinates of an impedance, $Z = 250 - j100$ ohms to polar coordinates we have in three steps:

$$\tan\theta = \frac{\text{opp}}{\text{adj}}$$

Substituting:

$$\tan\theta = \frac{-jX}{R}$$

$$= \frac{-100}{250} = -.4$$

and from our tables:

$$\theta = -21.8^\circ$$

(θ is negative because jX is negative.)

Then:

$$\sin\theta = \frac{\text{opp}}{\text{hyp}}$$

or:

$$\text{hyp} = \frac{\text{opp}}{\sin\theta}$$

Substituting:

$$Z = \frac{-jX}{\sin\theta} = \frac{100}{\sin 21.8^\circ}$$

$$= \frac{100}{.3714} = 269\Omega$$

Accordingly, in polar coordinates:

$$Z = 269\underline{/-21.8^\circ\Omega}$$

Notice that once we found θ, and since all the necessary values are available, we could have used:

$$\cos\theta = \frac{\text{adj}}{\text{hyp}}$$

instead of:

$$\sin\theta = \frac{\text{opp}}{\text{hyp}}$$

However, our answer would still have worked out to the same value of $269/-21.8^\circ\Omega$.

MULTIPLICATION AND DIVISION USING POLAR COORDINATES

You will recall from your study of operator j that complex quantitites can be multiplied and divided to form other complex quantities. For example, if both the current and impedance were known in an ac circuit, we can find the voltage by multiplying the current by the impedance:

$$E = I \times Z$$

To do this, we would use the following procedure (keeping in mind significant figures). Assume:

$$I = 1.72 + j.38 \text{ amperes}$$
$$Z = 246 - j12 \text{ ohms}$$
$$E = I \times Z$$

$$\begin{array}{rrrr}
 & (1.72 & + j.38) & \\
\times & (24.6 & - j\,12) & \\
\hline
 & 42.3 & + j9.35 & \\
 & & -j20.6 & + \;4.56 \\
\hline
 & 42.3 & -j11.3 & + \;4.56
\end{array}$$

$$= 46.9 - j11.3$$

$$E = 46.9 - j11.3 \text{ volts}$$

We can perform the same calculations using the polar form for the current and impedance. To do this we first convert the current and impedance expressions to polar form:

$$I = 1.72 + j.38 = 1.76\underline{/+12.5}$$
$$Z = 24.6 - j12 = 27.4\underline{/-26^\circ}$$

The rules for multiplication in polar form are:

1. *Multiply* the magnitudes.
2. *Add* the angles.

Using the figures for I and Z already determined, we obtain:

$$E = 1.76 \times 27.4\underline{/(+12.5) + (-26)}$$
$$E = 48.3\underline{/-13.5^\circ}$$

To check our calculation, we can convert $48.3\underline{/-13.5^\circ}$ to get rectangular form and we get $E = 46.9 - j11.3$ volts.

We can also divide using the polar form for complex numbers. You will recall that to divide complex numbers in rectangular form we multiply numerator and denominator by the conjugate of the denominator to remove the j term from the denominator. This is a long and complicated operation which can be simplified by using the polar form. The rules for division are:

1. ***Divide*** the magnitude of the numerator by the magnitude of the denominator.
2. ***Subtract*** the angle of the denominator from the angle of the numerator.

As an example, suppose we have $E = 123\underline{/20^\circ}$ and $I = 1.4\underline{/-46^\circ}$. To find the impedance we divide E by I:

$$Z = \frac{E}{I} = \frac{123\underline{/20^\circ}}{1.4\underline{/-46^\circ}} = 87.9\underline{/(20^\circ) - (-46^\circ)}$$

$$Z = 87.9\underline{/66^\circ} \text{ ohms}$$

As an exercise, convert E and I to rectangular form and perform the calculation using conjugates. Then see if your result is equal to $35.8 + j80.3$ ohms.

PHASORS AND SINE WAVES

In the lessons on alternating currents, you learned that an alternating current is sinusoidal in nature. In other words, the various values of current and voltage generated by an alternating current source describe what is called a sine wave which repeats itself periodically. However, we have not yet discussed what a sine wave is nor why ac current values produce it.

Additionally, in your first introduction to vectors, we mentioned that the vectors used in ac circuit calculations were not considered vectors by electronic engineers. In a most accurate technical sense, they are *phasors*. This is because vectors usually express force as magnitude and direction, while phasors represent sine wave values with respect to time or phase.

Since many of you learned to work with vectors in high school or college physics, and since vectors and phasors are treated the same in circuit computations, we will continue to call them vectors.

However, many modern engineering texts refer to electrical vectors as phasors and we should know why they are phasors. This is a good time to examine both the sine wave and electrical vectors in greater detail.

Angles Greater Than 90°. In studying trigonometry, we have considered the functions of angles only up to 90°. We can, however, have angles of any magnitude, depending on where the terminal side of an angle stops and on how many complete revolutions it makes in generating the angles. In our study of sine waves, we will need to consider the functions of all possible angles up to 360°.

To begin with, let's consider the sine of the acute angle θ shown in Fig. 22A. Since $\angle\theta$ is equal to 30°, the sine of θ is equal to the ratio of the length of the opposite side over the hypotenuse which always works out to .5.

Now let's consider the angle θ shown in Fig. 22B. Angle θ is equal to 150° which is larger than 90° and so cannot be one of the angles in a right triangle. We know that the trigonometric functions are based on the sides and angles of right triangles. Yet, $\angle\theta = 150^\circ$ is considered to have a sine function, even though it cannot be part of a right triangle. In fact, the sine of 150° is .5, just the same as the sine of 30°.

To see how this is determined, we must consider what is known as the "associated acute angle" of the angle θ. First of all, an angle is said to be in *standard position*

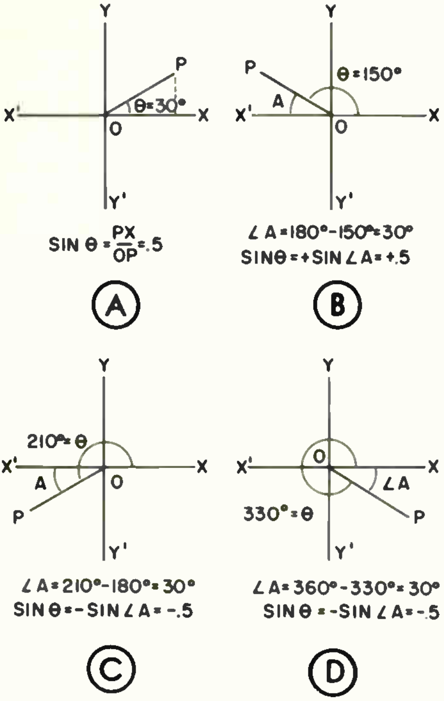


Fig. 22. Sines of angles greater than 90°.

when its *initial* side coincides with the *positive* side of the *X axis* of the standard coordinate reference frame, regardless of where its terminal side may be. Thus, the $\angle \theta = 150^\circ$ in Fig. 22B is in the standard position. Now, the ***associated acute angle*** of any angle θ larger than 90° is the acute angle which the terminal side of the angle makes with the X axis when the angle θ is in the standard position. Since $\angle \theta$ (Fig. 22B) is by definition in standard position, $\angle A$ is its associated acute angle. $\angle A$ is the supplement of $\angle \theta$, and therefore $\angle A = 180^\circ - \angle \theta (150^\circ)$ or 30°.

In Fig. 22C we have another angle θ which is equal to 210°. Its associated acute angle is $\angle A$ because, by definition, the associated acute angle is the acute angle formed between the terminal side and the X axis. Since θ equals 210°, and since the $\angle X'OX$ is equal to 180°, the $\angle A$ in Fig. 22C must be equal to $210^\circ - 180^\circ$ or $\angle A = 30^\circ$ again.

In Fig. 22D, we show still another angle θ. This time $\angle \theta = 330^\circ$ and its associated acute angle, $\angle A$, must equal $360^\circ - 330^\circ$ or 30° once again.

Remember, the associated acute angle always lies between the terminal side of $\angle \theta$ and the X axis as shown in Fig. 22. Notice that from this definition, $\angle \theta$ in Fig. 22A is really its own associated acute angle.

There is a trigonometric statement that says:

The function of any angle greater than 90° is equal to plus or minus the function of its associated acute angle.

This simply means that a 150° angle has the same sine as its associated acute angle, which is $\angle A$. Since $\angle A$ is 30°, the sine of the 150° angle is the same as the sine of the 30° angle. Likewise, the sine of 210° is equal to the sine of 30° except that it is negative, and the sine of 330° is also equal to the sine of 30° except that it is negative.

To determine the sine of any angle greater than 90°, find the value of the function of its associated acute angle. Then affix a plus or minus sign, depending on the quadrant in which the terminal side of the angle lies.

As you have probably guessed, all the other functions can also exist for any angle greater than 90°. The rule for the sine function applies to the other functions as well.

In Fig. 23A, the cosine of $\angle \theta = 252^\circ$ is equal to minus the cosine of 72° or $-.3090$ because 72° is the associated acute angle of 252° and the terminal side lies in the third quadrant. Likewise, the tangent of $\angle \theta = 305^\circ$ is equal to minus

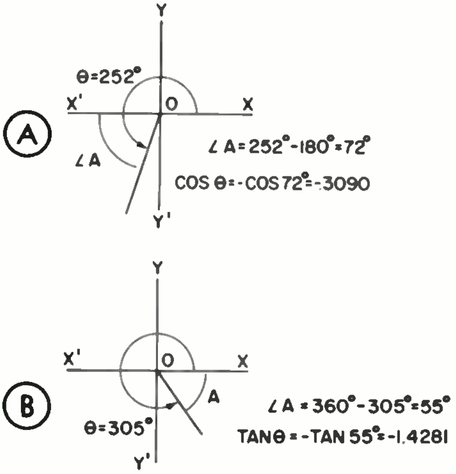


Fig. 23. All functions exist for all angles.

the tangent of 55° or −1.4281, as shown in Fig. 23B.

Now let's consider the sign of the functions in the different quadrants.

SIGNS OF FUNCTIONS IN QUADRANTS

In the first quadrant, all six functions are positive. In the second quadrant, the sine and cosecant are positive, all other functions are negative. In the third quadrant the tangent and its reciprocal (the cotangent) are positive and the other functions are negative. In the fourth quadrant, the cosine and secant are positive and the other four functions are negative.

To see why the functions have these signs, look at Fig. 24. First consider that the X–X′ axis and the Y–Y′ axis divide the figure into four quadrants. A line drawn from the Y–Y′ axis along or parallel to the X axis is considered positive if it is drawn to the right, and negative if it is drawn to the left. Similarly, a line drawn from the X–X′ axis along or parallel to the Y axis is positive if it is drawn upward and negative if it is drawn below the X–X′ axis.

Now look at angle θ in Fig. 24A. Side a is positive because it is drawn above the X–X′ axis, and side b is also positive because it is drawn to the right of the Y–Y′ axis. *The hypotenuse of the triangle is always considered positive* and therefore the functions are as follows:

$$\sin\theta = \frac{+a}{+c}$$

$$\cos\theta = \frac{+b}{+c}$$

$$\tan\theta = \frac{+a}{+b}$$

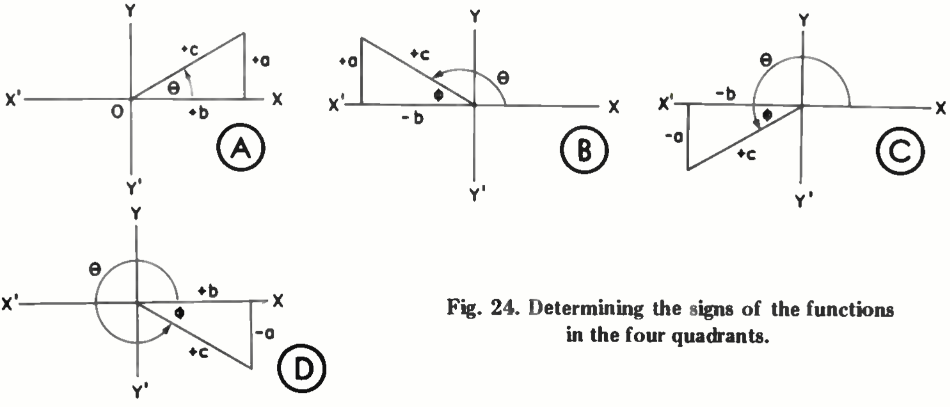


Fig. 24. Determining the signs of the functions in the four quadrants.

$$\cot\theta = \frac{+b}{+a}$$

$$\sec\theta = \frac{+c}{+b}$$

$$\csc\theta = \frac{+c}{+a}$$

In each case we have a plus term divided by another plus term, so the result in each case is positive.

Now look at Fig. 24B and consider the second quadrant. Again we are interested in angle θ. The functions are equal to the functions of the associated acute angle which we have labeled Φ (Greek capital letter Phi). The hypotenuse c is always positive. Side a which is parallel to the Y axis and drawn above the X–X′ axis is positive. Side b which is parallel to the X axis is drawn to the left of the Y–Y′ axis and is therefore negative. So now the functions are as follows:

$$\sin\theta = \sin\Phi = \frac{+a}{+c}$$

$$\cos\theta = -\cos\Phi = \frac{-b}{+c}$$

$$\tan\theta = -\tan\Phi = \frac{+a}{-b}$$

$$\cot\theta = -\cot\Phi = \frac{-b}{+a}$$

$$\sec\theta = -\sec\Phi = \frac{+c}{-b}$$

$$\csc\theta = \csc\Phi = \frac{+c}{+a}$$

From this you can see that the sin and csc will be positive because you have a plus term divided by another plus term and the other four functions will be negative because in each of these expressions there is one plus term and one negative term.

Now look at θ in the third quadrant shown in Fig. 24C. The hypotenuse c is positive, but now both a and b are negative. Therefore:

$$\sin\theta = -\sin\Phi = \frac{-a}{+c}$$

$$\cos\theta = -\cos\Phi = \frac{-b}{+c}$$

$$\tan\theta = \tan\Phi = \frac{-a}{-b}$$

$$\cot\theta = \cot\Phi = \frac{-b}{-a}$$

$$\sec\theta = -\sec\Phi = \frac{+c}{-b}$$

$$\csc\theta = -\csc\Phi = \frac{+c}{-a}$$

In the case of the tan and cot functions you have a minus term divided by a minus term which gives you a plus result so the tangent and cotangent are positive in the third quadrant and all other terms are negative.

Now look at θ in the fourth quadrant as shown in Fig. 24D. Again c is positive. Side b will also be positive, but side a is negative. Therefore:

$$\sin\theta = -\sin\Phi = \frac{-a}{+c}$$

$$\cos\theta = \cos\Phi = \frac{+b}{+c}$$

$$\tan\theta = -\tan\Phi = \frac{-a}{+b}$$

$$\cot\theta = -\cot\Phi = \frac{+b}{-a}$$

$$\sec\theta = \sec\Phi = \frac{+c}{+b}$$

$$\csc\theta = -\csc\Phi = \frac{+c}{-a}$$

Thus cos and sec are positive and the other four functions are negative in the fourth quadrant.

The Sine Wave. Now that we can determine the sine of any angle up to 360°, we are ready to continue with the definition of a sine curve. A sine curve is merely a graph of all the sines of all the angles up to 360° that repeats itself periodically. Since there are an infinite number of angles that can be formed between 0° and 360° (if all the possible stopping points of the terminal side are considered), there are also an infinite number of sine functions to plot a curve. Therefore, we simply choose angles in 15° steps from 0° to 360° and plot their functions. We then round off the sine functions of these angles to two decimal places because this is as accurate as we can be if we are to keep the graph to a reasonable size.

Now let's examine and list the sine functions of the angles, starting with $\angle\theta = 0°$. When θ equals zero, there is no angle or opposite side, so when $\angle\theta$ equals 0°, the opposite side must also be zero. Therefore, since $\sin\theta$ equals the ratio of opp/hyp, and $\sin\theta$ equals the ratio of 0/hyp, when $\angle\theta$ equals 0°, $\sin\theta$ must also equal 0. Therefore, our list of functions begins with:

$$\theta = 0°; \quad \sin\theta = 0$$

We have seen that the ratio of opp/hyp is always equal to the sine of $\angle\theta$ as listed in the tables, no matter what the relative lengths of the sides of the right triangle may be. Therefore, you can use the tables directly to make a list of the sine functions of all the angles you wish to use.

The next step is to lay out a graph as shown in Fig. 25. Here the base line is laid out on the X axis and is marked in 15° steps from 0° to 360°. The numbers 0 to 1.0 are laid out vertically in steps of

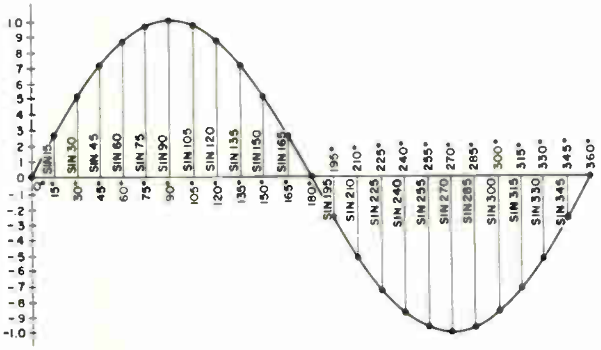


Fig. 25. Graphical plot of the sines of angles in 15° steps from 0° to 360°.

.1 in the positive direction along the Y axis. The numbers from 0 to −1.0 are laid out in steps of −.1 in the negative direction along the Y axis. At each 15° step along the X axis, the appropriate value of the sine of the angle is indicated in terms of the numbers located on the Y axis. Thus, we have a graph of ***various values*** of the Y values of the sines of all the angles indicated along the X axis. This is generally called a graph of Y = sin X.

When these points are joined with a smooth curve, a curve is formed which represents the sines of all the angles between 0° and 360°. This is called a sine curve or sine wave. We can consider the terminal side of angles generated to form a sine curve as a rotating vector, as shown in Fig. 26. This rotating vector generates the angles and consequently the functions of the angles indicated by the sine curve. If sine θ equals

$$\frac{\text{opp}}{\text{hyp}}$$

and hyp (rotating vector) equals 1 unit, then sin θ equals

$$\frac{\text{opp}}{1} = \text{opp}$$

Thus, if this vector equals 1″, 1′, 1 volt, or any other value, the sine functions generated will be equal to the length of the perpendiculars, which will also equal the actual value of the sine functions as listed in the tables.

Notice that as the vector starts from 0°, the function is 0; as it passes through 90° the maximum function is generated. At 180° the function is again 0; at 270° in the negative direction it is maximum; and at 360° it is back again to no function. Also notice that the value of the function changes most rapidly when the vector is rotating through 0°, 180°, and 360°. This rotating vector can be compared to the rotation of the armature of a basic ac generator as shown in Fig. 27.

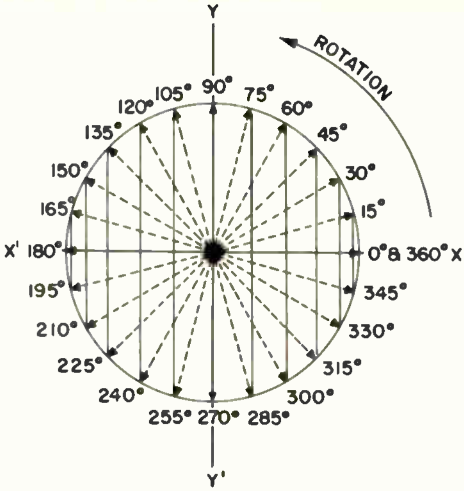


Fig. 26. Diagram of rotating vector generating sine functions shown in the sine curve of Fig. 25.

As the armature moves parallel to the lines of force as shown in Fig. 27A, no voltage will be generated. As it moves at right angles to the lines of force as in Fig. 27B, the maximum number of lines of force will be cut and the maximum voltage will be generated. While it is

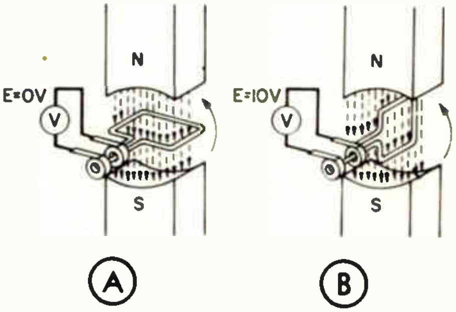


Fig. 27. Generator armature can be compared to rotating vector in Fig. 26.

moving from its position shown in Fig. 27A to that shown in Fig. 27B, the voltage generated will increase from zero to maximum in proportion to the sine of its instantaneous angular position. Thus, if we consider the maximum voltage as 10 volts at 90° of rotation as shown in Fig. 27B, and zero voltage as 0 volts at 0° of rotation as shown in Fig. 27A, the instantaneous value of voltage at a rotation of 15° would be 2.7 volts. It would be 5 volts at 30°, 7.1 volts at 45°, etc. If we were to measure all these instantaneous voltages at each 15° step of angular rotation of the basic armature in a standard magnetic field from 0° through 360°, we would obtain a sine wave graph similar to the one in Fig. 25. This is why an ac voltage is said to vary sinusoidally, and is called a sine wave.

If the armature continues to rotate again and again at the same speed, the sine wave voltage will repeat itself indefinitely. We will get a complete 0° – 360° sine wave during each complete revolution or period, so the sine wave is a periodic repetition of the same functions.

Phase Relationships. We have seen how the voltage generated by the rotating armature describes a sine wave just as the sine functions of the rotating vector describe the sine curve of the angles it passes through. Now suppose we have two generators represented by rotating vectors, as shown in Fig. 28. They are exactly the same except that when one armature is passing through 90° the other is passing through 0°. The sine wave outputs of the two generators are superimposed on each other as shown by the solid and dotted sine waves in Fig. 29.

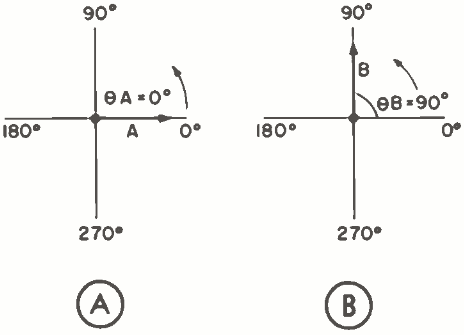


Fig. 28. Two generators represented by rotating vectors. (A) shows instantaneous value of sin θ to be zero. (B) shows instantaneous value of sin θ to be maximum at the same instant.

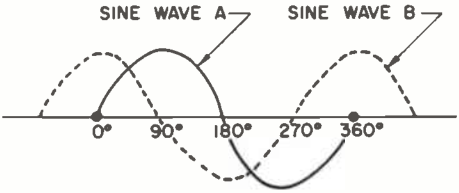


Fig. 29. Sine waves generated by two identical phasors operating 90° apart.

As you can see, these voltage sine waves are generated 90° out-of-phase with each other just as the vectors are 90° out-of-phase. Thus, the rotating vectors represent the relative phase of the two sine waves and are called phasors. By applying the principles of trigonometry to the angle generated by one of the phasors, we can determine the instantaneous value of voltage generated for any position of the phasor if we know its value at $\sin \theta = 1$.

Thus, if at $\sin \theta = 1$, or 90°, the phasor produces a voltage of 120 volts, then at $\angle \theta = 30$, the instantaneous value of voltage generated will equal

$$\sin \theta = \frac{\text{opp}}{\text{hyp}}$$

And, hyp equals phasor length at $\sin \theta = 1$, therefore hyp equals 120. Then,

$$\sin \theta = \frac{\text{opp}}{120}$$

and θ equals 30°, therefore

$$\sin 30^\circ \text{ or } .5 = \frac{\text{opp}}{120}$$

and opp equals $120 \times .5 = 60$ volts of instantaneous voltage. In this way phasors can be used to represent the instantaneous values of all the sine wave voltages occurring across circuit components at any instant.

Phasors can be expressed in rectangular coordinates as well as polar coordinates All the principles of the parallelogram measurement method for solving vector diagrams can be applied to phasors. Similarly, the j operator and trigonometry can be used in the solution of phasor problems. Consequently, we shall continue to call our phasors "vectors" in this course. Remember, however, that although a phasor can perhaps be considered a special type of vector as is done in most older texts, a vector cannot be considered a phasor.

SELF-TEST QUESTIONS

16. A 15-ohm resistor is connected in series with a 15-ohm capacitive reactance. What is the impedance of the circuit? Express your answer in both polar and binomial form.
17. R_1, R_2, C_1, C_2, L_1 and L_2 are connected in series. $R_1 = 10$ ohms, $R_2 = 30$ ohms, $X_{C1} = 9$ ohms, $X_{C2} = 16$ ohms, $X_{L1} = 20$ ohms, $X_{L2} = 35$ ohms. What is the impedance? Express your answer in both polar and binomial form.
18. In the Cartesian coordinate system,
    (a) in which quadrants is X positive?
    (b) in which quadrants is Y positive?
    (c) in which quadrants are both X and Y negative?
19. What is the value of
    (a) sin 150°?
    (b) cos 150°?
20. What is the value of
    (a) tan 135°?
    (b) cot 225°?
21. What is the value of
    (a) sin −60°?
    (b) cos −60°?
22. Express the following polar coordinates as rectangular coordinates.
    (a) $6\underline{/36^\circ}$
    (b) $5\underline{/-50^\circ}$
23. Convert the following rectangular coordinates into polar coordinates.
    (a) (5, −11)
    (b) (−6, −7)
24. Convert 11 + j15 ohms to polar form.
25. Convert 7 − j4 ohms to polar form.
26. Convert $9\underline{/-50^\circ}$ ohms to j-operator form.
27. Convert $12\underline{/32^\circ}$ ohms to j-operator form.

Trigonometry in AC Circuits

In an earlier part of this lesson we saw how trigonometry is used in simple series circuit calculations. In this section we will apply what we have learned about vector diagrams, the j operator, algebra, and trigonometry to more complicated ac circuits. Before discussing series parallel circuits, let's take a look at a series circuit and get familiar with voltage computations.

Resistance in Coils. Until now we have neglected the resistance that exists in the windings of coils in our ac circuit calculations. Although we can do this without being too far off, occasionally we will want to be more accurate. This does not present any particular problem where both the resistance and either the inductance or inductive reactance of the coil are given. However, in many circuits, this information is not easy to obtain. Although, it is easy to measure the resistance of a coil with an ohmmeter, the inductance cannot be found as easily unless we have a special meter.

However, through the use of trigonometry and standard measuring instruments, it is quite easy to determine the inductance of a coil and separate the inductive reactance from the resistance. For example, consider the circuit shown in Fig. 30. Here we have a coil, a capacitor, and a resistor in series with each other. If we measure the voltage drops across each of these units as shown, and then compute the total voltage of the circuit, we will find that the total voltage computed does not agree with the total voltage indicated by the measurement. Let's see why this difficulty occurs and how to overcome it.

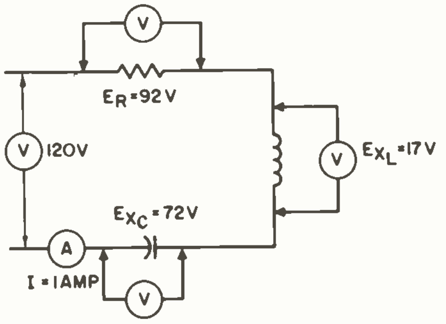
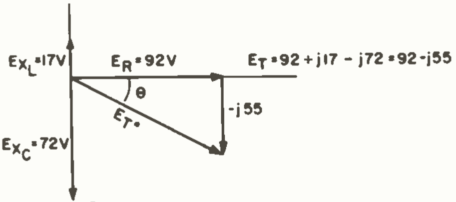


Fig. 30. Typical series circuit voltage measurements.



$$\text{TAN } \theta = \frac{\text{Opp}}{\text{Adj}} = \frac{55}{92} = .5978 = \text{TAN } 30.868^\circ \text{ or } 30.9^\circ$$

$$\theta = 30.9^\circ$$

$$\text{SIN } \theta = \frac{\text{Opp}}{\text{Hyp}} = \frac{55}{E_T}$$

$$E_T = \frac{55}{\text{SIN } 30.9^\circ} = \frac{55}{5135} = 107.1 \text{ VOLTS}$$

Fig. 31. Computation of total voltage without considering coil resistance.

First, computing the total voltage, E_T, without considering any possible resistance that the coil might have, we get the results shown in Fig. 31. Drawing our rough vector diagram as shown, we have E_{X_L} of 17V as the inductive vector component, E_{X_C} of 72V as the capacitive vector component, and E_R of 92V as the resistive vector component. Mathematically, this gives us: 92 + j17 – j72, or 92 – j55 as our final vector stated as a binomial. Thus, E_T is the hypotenuse of a right triangle with a base of 92V and an altitude of 55V. Then, using trigonometry, we find that the phase angle θ equals:

$$\tan\theta = \frac{\text{opp}}{\text{adj}} = \frac{55}{92} = .5978$$

Therefore:

$$\theta = \text{angle whose tangent is } .5978$$

By using our Table of Functions and interpolating we find that the angle θ equals 30.9°.

Now that we have the angle θ, we can find the value of E_T through the function:

$$\sin\theta = \frac{\text{opp}}{\text{hyp}} \text{ or hyp} = \frac{\text{opp}}{\sin\theta}$$

or $$E_T = \frac{55}{\sin 30.9^\circ}$$

Since our table lists the functions in one-degree steps we must interpolate to find the sine of 30.9°. Doing this, we find:

$$\sin 30.9^\circ = .5135$$

Substituting:

$$E_T = \frac{55}{\sin 30.9^\circ}$$

$$= \frac{55}{.5135} = 107.1 \text{ volts}$$

Thus, by computing, we find that E_T = 107.1 volts, even though the measured value for E_T in the circuit of Fig. 30 is 120 volts. The reason for this difference is that the Q of the coil is low; therefore, the ratio of the resistance of its winding to its inductance is large. This means that the voltage E_{X_L}, which we assumed to be purely inductive, does not lead the current in the circuit by a full 90°. Consequently, our E_{X_L} of 17 volts is really voltage made up of $E_{R_L} + jE_{X_L}$ and cannot be written $+j17$ and added directly to our $-j72$. It must be broken down into its two components, $E_{R_L} + jE_{X_L}$. Thus, the vector diagram of our circuit must be drawn as shown in Fig. 32, and our voltage vector E_T must be found from:

$$E_T = E_R + E_{T X_L} - jE_{X_C}$$

and

$$E_T = E_R + (E_{R_L} + jE_{X_L}) - jE_{X_C}$$

$$= 92 + E_{R_L} + jE_{X_L} - j72$$

In order to work out a solution to this problem, we must know the values of both E_{R_L} and E_{X_L}. Neither the value of the resistance of the coil nor the value of its inductance is given. However, the chances are that if we have a meter or meters capable of reading the voltages of the circuit and the current through the circuit, as shown in Fig. 30, we will also

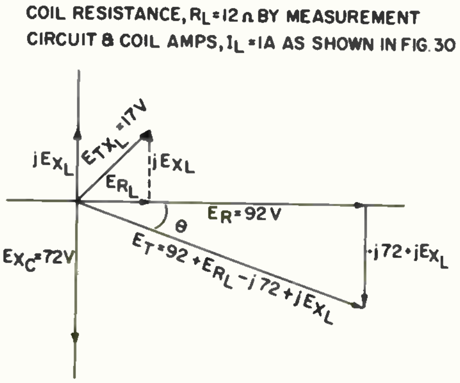


Fig. 32. Vector diagram of circuit in Fig. 30 considering coil resistance.

have an ohmmeter. With the ohmmeter we can determine the resistance of the coil, and then by computing we can find E_{R_L} and E_{X_L}.

For example, suppose we measure the resistance of the coil and find it to be 12 ohms. Our circuit ammeter shows us that the current through the circuit is 1 amp. Thus,

$$\begin{aligned} E_{R_L} &= I \times R_L \\ &= 1 \times 12 \\ &= 12 \text{ volts} \end{aligned}$$

This gives us one of our components of E_{X_L}, so our equation for E_T becomes:

$$\begin{aligned} E_T &= 92 + E_{R_L} + jE_{X_L} - j72 \\ &= 92 + 12 + jE_{X_L} - j72 \end{aligned}$$

Now, all we have left to determine is the value of jE_{X_L}.

This is where trigonometry really helps. We have the total coil voltage drop and have been able to compute the resistance component of this total drop. Therefore, we have the value of both the hypotenuse and the base of a right triangle as shown in Fig. 33A, and can compute the value of jE_{X_L}. First we list our values as:

Given: $E_{TX_L} = 17\text{V}$

$I_L = 1\text{A}$

$R_L = 12$ ohms

$$\begin{aligned} E_{R_L} &= I_L \times R_L \\ &= 1 \times 12 \\ &= 12\text{V} \end{aligned}$$

Find: E_{X_L}

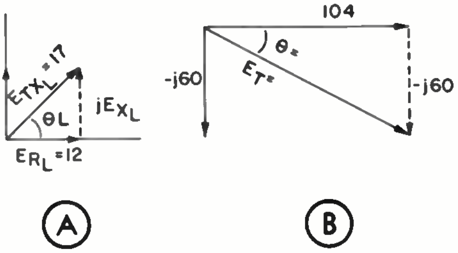


Fig. 33. Trigonometric solution of vector diagram of Fig. 32.

Now, sketching the vector diagram with 17 as the hypotenuse and 12 as the base of a right triangle, as shown in Fig. 33A, allows us to use our trigonometry. First we want to find the phase angle θ_L. To do this, we use the cosine function which is:

$$\cos\theta = \frac{\text{adj}}{\text{hyp}} = \frac{E_{R_L}}{E_{TX_L}} = \frac{12}{17} = .7057$$

In checking our Table of Functions we find that there is no cosine given as exactly .7057. Although we could interpolate to find the exact value for θ, our cosine of .7057 is so close to .7071, which is the cosine of 45°, that we can use the approximate value of 45° as the angle θ_L.

Now that we know that θ_L is equal to 45°, we can proceed to find the value of jE_{X_L} (the opposite side) by using one of the other functions. For example,

$$\tan\theta_L = \frac{\text{opp}}{\text{adj}}$$

and:

$$\text{opp} = \text{adj} \times \tan \theta_L$$

Substituting:

$$jE_{X_L} = E_{R_L} \times \tan 45^\circ$$

$$jE_{X_L} = 12 \times 1.0000 = 12$$

Thus, jE_{X_L}, which is the reactive component of the total coil voltage, is also equal to 12 volts. Notice that we could also have used the sine since

$$\sin \theta_L = \frac{\text{opp}}{\text{hyp}}$$

and therefore

$$\text{opp} = \sin \theta_L \times \text{hyp}$$

or

$$jE_{X_L} = \sin 45^\circ \times E_{TX_L}$$

$$= .7071 \times 17 = 12 \text{ (approx.)}$$

The function used is a matter of personal choice or convenience as long as the necessary values are known.

Notice what we have done. We took a voltage drop across a coil and broke it up into its resistive and reactive components. We could not measure these components because they do not exist separately; they exist together as a total. The fact that this vector sum is not exactly in phase with the current tells us that it must have both of the components. In order to ***compute*** the circuit values accurately, we must have the values of the components, not their vector sum. Since the resistance of a coil, the current through the coil, and the total voltage across the coil are all easy to measure with instruments, we have used these values, together with trigonometry, to obtain the two components of total coil voltage.

If we have the inductance or the inductive reactance of the coil, we can also use them to compute the value of the components. However, in practical circuits the value of the inductance or inductive reactance is often not known. Since these values can only be measured with instruments, which are usually not available in the average shop, we have shown you a method to use to solve the problem.

Since we now have all the values required to find E_T as shown in Fig. 32, we can continue with our computation as shown in Fig. 33B. We have already established the fact that:

$$E_T = E_R + E_{TX_L} - jE_{X_C}$$

By substitution:

$$E_T = E_R + (E_{R_L} + jE_{X_L}) - jE_{X_C}$$

and:

$$E_T = 92 + 12 + j12 - j72$$

Then:

$$E_T = 104 - j60$$

and we can draw the vector diagram as shown in Fig. 33B and compute the value of E_T and θ by using trigonometry. First:

$$\tan \theta = \frac{\text{opp}}{\text{adj}} = \frac{60}{104} = .5769$$

and

$$\theta = 30^\circ \text{ (approx.)}$$

Then:

$$\sin\theta = \frac{\text{opp}}{\text{hyp}}$$

and

$$\text{hyp} = \frac{\text{opp}}{\sin\theta} = \frac{60}{.5} = 120\text{V}$$

This is the value of E_T that we obtained by measurement in Fig. 30 and is therefore correct.

We have used a very low Q coil to demonstrate the importance of considering the resistive component of voltage in a coil.

$$Q = \frac{12}{12} = 1$$

Although such a low Q coil will not be found often in practical circuits, it is still important to know how to handle these effects when they do occur. You are probably wondering about the resistance of capacitors and if it too has to be considered. It does not. Although all capacitors do have some resistance, it is never large enough to be noticed in a practical capacitor.

SERIES-PARALLEL CIRCUITS

Now let's look at a more complicated circuit, such as the one shown in Fig. 34. This is a series-parallel circuit with the various values given. We are asked to find the total impedance Z_T, the total current I_T, and the final phase angle θ_T.

First, we want to find the impedance of the three parallel branches, a, b, and c, which we can do as follows:

$$Z_a = R + jX_L = 25 + j17.5 \text{ ohms}$$

$$\tan\theta_a = \frac{\text{opp}}{\text{adj}} = \frac{X_{La}}{R_a} = \frac{17.5}{25} = .700$$

$$\theta_a = 35^\circ$$

Then:

$$\sin\theta_a = \frac{\text{opp}}{\text{hyp}} = \frac{X_{La}}{Z_a}$$

or

$$Z_a = \frac{X_{La}}{\sin\theta_a} = \frac{17.5}{\sin 35^\circ}$$

$$= \frac{17.5}{.574} = 30.5 \text{ ohms}$$

Thus:

$$Z_a = 30.5\underline{/35^\circ} \text{ ohms}$$

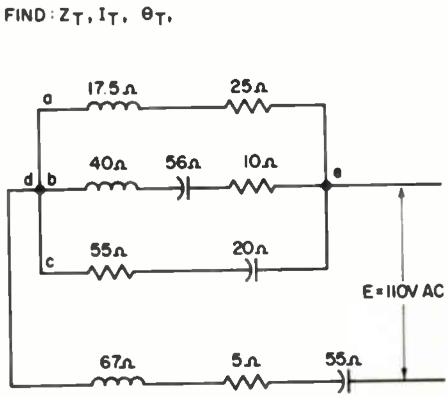


Fig. 34. Series-parallel ac circuit.

Next:

$$Z_b = R + jX_L - jX_c$$

$$= 10 + j40 - j56$$

$$= 10 - j16$$

$$\tan \theta_b = \frac{\text{opp}}{\text{adj}} = \frac{X_b}{R_b}$$

$$= \frac{-16}{10} = -1.6$$

$$\theta_b = -58^\circ$$

Then:

$$\sin \theta_b = \frac{\text{opp}}{\text{hyp}} = \frac{X_b}{Z_b}$$

or

$$Z_b = \frac{X_b}{\sin \theta_b} = \frac{-16}{\sin -58^\circ}$$

$$= \frac{-16}{-.848} = 18.9$$

Thus:

$$Z_b = 18.9\angle{-58^\circ} \text{ ohms}$$

Next:

$$Z_c = R - jX_c = 55 - j20$$

$$\tan \theta_c = \frac{\text{opp}}{\text{adj}} = \frac{-20}{55} = -.364$$

$$\theta_c = -20^\circ$$

Then:

$$\sin \theta_c = \frac{\text{opp}}{\text{hyp}} = \frac{X_c}{Z_c}$$

or

$$Z_c = \frac{X_c}{\sin \theta_c} = \frac{-20}{\sin -20}$$

$$= \frac{-20}{-.342} = 58.5$$

Thus:

$$Z_c = 58.5\angle{-20^\circ} \text{ ohms}$$

Now assume a voltage between d and e and find I for each branch as follows:

$$I_a = \frac{E_{de}}{Z_a} = \frac{100\angle{0^\circ}}{30.5\angle{35^\circ}} = 3.28\angle{-35^\circ} \text{ amps}$$

$$I_b = \frac{E_{de}}{Z_b} = \frac{100\angle{0^\circ}}{18.9\angle{-58^\circ}} = 5.3\angle{58^\circ} \text{ amps}$$

$$I_c = \frac{E_{de}}{Z_c} = \frac{100\angle{0^\circ}}{58.5\angle{-20^\circ}} = 1.71\angle{20^\circ} \text{ amps}$$

Now convert branch currents I_a, I_b, and I_c from polar to rectangular coordinates for easy addition as follows:

$$\begin{aligned} I_a &= I_a (\cos \theta_a + j \sin \theta_a) \\ &= 3.28 (\cos -35^\circ + j \sin -35^\circ) \\ &= 3.28 (.8192 - j.5736) \\ &= 2.69 - j1.88 \text{ amps} \end{aligned}$$

Since -35° lies in the fourth quadrant, cos -35° is positive and sin -35° is negative. This explains why the resistive term is positive and the reactive term is negative.)

$$\begin{aligned}I_b &= I_b(\cos\theta_b + j\sin\theta_b)\\ &= 5.3(\cos 58^\circ + j\sin 58^\circ)\\ &= 5.3(.5299 + j.8480)\\ &= 2.81 + j4.5 \text{ amps}\end{aligned}$$

$$\begin{aligned}I_c &= I_c(\cos\theta_c + j\sin\theta_c)\\ &= 1.71(\cos 20^\circ + j\sin 20^\circ)\\ &= 1.71(.9397 + j.3420)\\ &= 1.61 + j.585 \text{ amps}\end{aligned}$$

Now,

$$I_{de} = I_a + I_b + I_c$$

and:

$$\begin{array}{l} I_a = 2.69 - j1.88\\ I_b = 2.81 + j4.5\\ \underline{I_c = 1.61 + j.585}\end{array}$$

thus,

$$I_{de} = 7.11 + j3.205$$

Now

$$\tan\theta_{de} = \frac{\text{opp}}{\text{adj}} = \frac{I_{de_x}}{I_{de_r}}$$

$$= \frac{3.2}{7.11} = .45$$

$$\theta_{de} = 24.2^\circ$$

And I_{de} in polar form:

$$\sin\theta_{de} = \frac{\text{opp}}{\text{hyp}} = \frac{I_{de_x}}{I_{de}} \text{ or } I_{de} = \frac{I_{de_x}}{\sin\theta_{de}}$$

Then:

$$I_{de} = \frac{I_{de_x}}{\sin\theta_{de}} = \frac{3.2}{\sin 24.2^\circ}$$

$$= \frac{3.2}{.4099} = 7.8$$

Thus:

$$I_{de} = 7.8\underline{/24.2^\circ} \text{ amps}$$

And:

$$Z_{de} = \frac{E_{de}}{I_{de}} = \frac{100\underline{/0^\circ}}{7.8\underline{/24.2^\circ}}$$

$$= 12.8\underline{/-24.2^\circ} \text{ ohms}$$

Converting Z_{de} to rectangular coordinates:

$$\begin{aligned}Z_{de} &= Z_{de}(\cos\theta_{de} + j\sin\theta_{de})\\ &= 12.8(\cos -24.2 + j\sin -24.2^\circ)\\ &= 12.8(.9121 - j.4099)\\ &= 11.7 - j5.25 \text{ ohms}\end{aligned}$$

Now combining:

$$\begin{aligned}Z_T &= Z_{de} + j67 - j55 + 5\\ Z_T &= 11.7 + 5 - j5.25 + j67 - j55\\ Z_T &= 16.7 + j6.75 \text{ ohms}\end{aligned}$$

Then:

$$\tan\theta_T = \frac{\text{opp}}{\text{adj}} = \frac{6.75}{16.7} = .404$$

$$\theta_T = 22^\circ$$

Converting Z_T to polar form:

$$\sin\theta_T = \frac{\text{opp}}{\text{hyp}} = \frac{X_T}{Z_T}$$

or

$$Z_T = \frac{X_T}{\sin\theta_T} = \frac{6.75}{\sin 22^\circ} = \frac{6.75}{.3746} = 18$$

$$Z_T = 18\underline{/22^\circ} \text{ ohms}$$

Then:

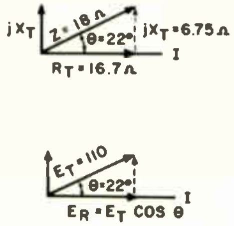
$$I_T = \frac{E_T}{Z_T} = \frac{110\underline{/0^\circ}}{18\underline{/22^\circ}}$$

$$= 6.11\underline{/-22^\circ} \text{ amps}$$

With this as a typical example of using trigonometry in ac circuits, try some of the problems you solved using the j-operator and the Pythagorean Theorem in your previous lessons.

Power in AC Circuits. Up until now we have not considered power in ac circuits because we have not had a simple method of finding it. In a purely resistive circuit, where the current and voltage are in phase, the power is equal to the voltage times the current as it is in a dc circuit. In a purely reactive circuit where there is no resistance whatsoever, power is alternately stored up by the reactive elements and then returned to the line. Such a circuit can exist only in theory, of course, because practical circuits always have some resistance. However, oscillatory tank circuits, which you have studied, do come fairly close to being resistance-free and, consequently, small properly timed surges of current can keep them going indefinitely.

Thus, we can say that the resistive elements of a circuit consume the only power expended. Let's see what this means in terms of the circuit we have just studied. If we construct the resultant vector diagram of the circuit from $\theta_T = 22^\circ$, $Z_T = 18\Omega$, we have a vector $Z_T = 18\underline{/22^\circ}$ as shown in Fig. 35. The reactive component of this impedance is jX_T as shown, and the resistive component is equal to R_T as shown. The resistive component is equal to 16.7 ohms, while the reactive component is 6.75 ohms, as we discovered while solving for Z_T.



$P = EI \cos\theta$

$P_a = EI$

$P.F. = \cos\theta$

Fig. 35. Vector representation of power factor.

Now, if the resistive component is all that consumes power, the power must be equal to $E_R \times I$ since only the resistive component of voltage forces current through the resistance to consume power. However, in the circuit we have just solved, we are not given the value of E_R, nor did we find it in any of our computations. However, if we lay out a vector representing the conditions of our circuit, we have a vector of the total voltage E_T of 110V leading the current vector, which we have taken as our reference vector, by 22°. We can find E_R now by using:

$$\cos\theta = \frac{\text{adj}}{\text{hyp}} = \frac{E_R}{E_T}$$

and

$$E_R = E_T \cos\theta$$

Now, if $P = E_R \times I$ equals the power expended and $E_R = E_T \cos\theta$, by substitution:

$$P = (E_T \cos\theta)I$$

or

$$P = EI \cos\theta$$

Then, substituting values:

$$\begin{aligned} P &= 110 \times 6.11 \times \cos 22^\circ \\ &= 110 \times 6.11 \times .9272 \\ &= 623 \text{ watts} \end{aligned}$$

This is the power actually consumed by the circuit.

Now, in ac circuits we have another value of power which is called the apparent power. This is simply the product of E_T and I_T without considering their relative instantaneous values at any particular moment. Thus, in the circuit we have just solved, the apparent power is simply 110 × 6.11 or 672.1W. The apparent power in a circuit is designated as P_a to separate it from the true power P which does take into consideration the relative instantaneous values of E and I through multiplication by $\cos\theta$.

Now, we have another situation in ac power that must be considered. This is the power factor PF which is the ratio of the true power P to the apparent power P_a. Mathematically, this is stated:

$$PF = \frac{P}{P_a}$$

then

$$PF = \frac{EI\cos\theta}{EI} = \cos\theta$$

and the power factor can be found from $PF = \cos\theta$. In the circuit we have just computed, PF = .927 lagging because the current lags the voltage by 22°. Power factor is also expressed as a percentage, 92.7%.

There are other formulas for power factor in ac circuits, but these are the most common. Since the formula $P = I^2R$ uses only resistance and current, it will also give us the true power. Here we are not multiplying the effective values of current by an effective value of voltage without considering their relative instantaneous values. We are simply squaring the effective value of current and multiplying it by the total resistive component of Z. Thus, $P = I^2R$ gives us: $6.11^2 \times 16.7 = 623$ watts which is true power.

We can also write another formula for power factor. If

$$PF = \frac{P}{P_a}$$

and

$$P = I^2R$$

and

$$P_a = EI$$

Then:

$$PF = \frac{I^2R}{EI} = \frac{IR}{E}$$

But

$$E = IZ$$

so

$$PF = \frac{IR}{IZ} = \frac{R}{Z}$$

Therefore

$$PF = \frac{R}{Z}$$

However, this is just another way of saying $\cos\theta$, because

$$\cos\theta = \frac{adj}{hyp} = \frac{R}{Z}$$

It also should be noted that true power P equals PF × P_a because

$$PF = \frac{R}{Z} \text{ or } \cos\theta$$

and

$$P_a = EI$$

and our first formula for power was $P = EI \cos \theta$. Any of the relationships may be used, and if you remember that:

$$P_a = EI$$

and

$$P = EI \times PF$$

$$PF = \cos \theta$$

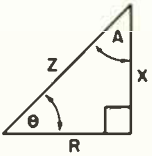
you can use algebra and trigonometry to work out the other formulas.

Although you will not become an expert in the science of trigonometry from what you have learned in this lesson, you have covered most of the basic fundamentals and their application in electronics. You will be able to handle nearly every problem when you understand the elementary principles of trigonometry. Like any other math, trig requires a lot of practice to become familiar with it. You should practice solving the right triangles of circuits in other lessons to obtain this practice.

Now answer the following Self-Test Questions which are an overall review of trigonometry. They will give you further practice in solving ac circuit problems.

SELF-TEST QUESTIONS

28. An angle is equal to 3 radians. What does it measure in degrees?
29. How many degrees are there in 1.7 radians?
30. Convert 15.6° to radians.
31. In the right triangle shown below side X is equal to 25 ohms and side R is equal to 76.0 ohms. What does side Z equal?



32. In the triangle shown above, if side Z equals 45 and $\angle \theta$ equals 45°, what does side X equal?
33. What is the sine of 345°?
34. In the triangle shown above, find $\angle \theta$ if $\sin \angle A = .4415$.
35. If the voltage of an ac circuit is leading the current by 35.8°, what is the power factor of the circuit?
36. If the total voltage applied to the circuit discussed in Question 35 is 220 volts and the current through the circuit is 1.79 amps, what is the true power consumed by the circuit?
37. When the impedance of a circuit is described as: $Z = 5\underline{/36.9^\circ}\Omega$ in polar coordinates, how would you express it in rectangular coordinates?
38. A choke coil draws 2 amps of current when it is connected across 110V dc. When connected to 110V, 60 cycles ac, the current drawn is .25 amp. What is the resistance and the inductive reactance of the coil?
39. The following 60-Hertz impedances are connected in series:
    $Z_1 = 3 - j6\Omega$
    $Z_2 = 10 + j19\Omega$
    $Z_3 = 2 - j7\Omega$
    $Z_4 = 5 + j14\Omega$
    What is the impedance of the circuit in polar coordinates?
40. In the circuit described in Question 39, what value of capacitance would we have to add to the circuit to make

the power factor 70.7% leading?

41. A supply of 220 volts ac is applied to an impedance of $Z_a = 55\underline{/40^\circ}\Omega$ in parallel with an impedance of $Z_b = 71\underline{/-36^\circ}\Omega$. What is the power consumed in Z_b?

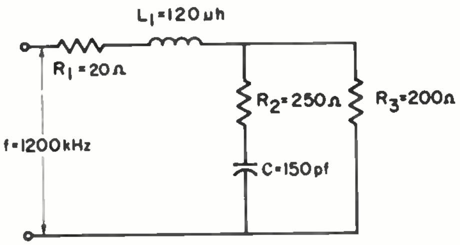
42. In the circuit shown, what is the total impedance?

43. In the circuit shown below, find the total impedance of the circuit.

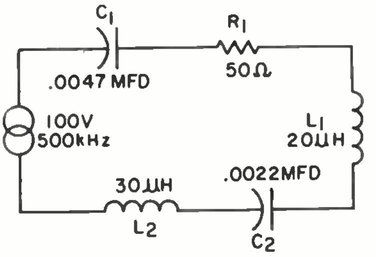
44. Find the total current in the circuit shown below.

45. Find the power dissipated in the circuit shown below.

46. Find the power dissipated by R_1 in the circuit shown below.



Circuit for Question 42.



Circuit for Questions 43, 44, 45, and 46.

Graphs

A graph is a picture that shows the effect of changes in one variable on a second variable. Graphs are very common in electronics literature since they provide a simple means of describing circuit operations, illustrating equations and formulas, showing relationships when no formulas exist, and displaying results of experiments.

Graphs are not new to you; you studied them in grade school. They are commonly used in newspapers to show economic trends. Although the same things could be shown with columns of figures, the line on a graph puts the idea over much better. It is hard to visualize trends or patterns from a column of figures, but a line on a graph lays the pattern out in front of you in a way that is easy to grasp.

USING GRAPHS

The most common type of graph is drawn on paper ruled with uniformly spaced horizontal and vertical lines. This type of paper is known as ***rectilinear*** or ***cross section*** or just plain graph paper. Cross-sectional paper is available with many different line spacings, but 4, 5, 10, and 20 lines per inch are the most common.

The data for plotting graphs may be obtained by measurements of both quantities. Or the data may be obtained by repeated solutions of a formula. A graph with two plots obtained in the latter manner is shown in Fig. 36. This graph shows the voltage across a 75-ohm resistor and the power dissipated in it for different values of current.

Fig. 36 was plotted by assuming different values for the current and calculating the corresponding voltage drops and power dissipations using the formulas shown. Since the calculated values of voltage and power depend on the assumed values of the current, voltage and power are called the ***dependent variables***. The current could be given any desired value and changed at will, so current is called the ***independent variable***. Following custom, the dependent variable is scaled along the vertical axis, and the independent variable is scaled along the horizontal axis.

Several important things about graphs are illustrated here. Both scales are labeled to show the quantity they represent, and the units in which that quantity is measured. The values assigned to each division of the scales are marked along them. Note that the two scales are not equally divided; one division of the horizontal scale is equal to .05 units and one division on the vertical scale equals 5 units. Each plot is labeled with the

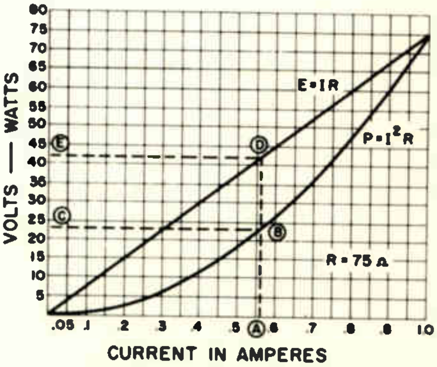


Fig. 36. Change in voltage across, and power in a 75-ohm resistor as current changes.

formula used to obtain the data. The formulas also serve as titles, telling what the graph shows. The value of the resistance used in the calculation completes the labeling. All the information needed to use or identify this graph appears upon it. Nothing is left to memory or imagination. Without this information no graph is complete.

Graphs like Fig. 36 are frequently made up to avoid repeated computations. For example, suppose you are checking the effect of changing tube voltages on the output of an amplifier. You are measuring the output with an ammeter in series with the 75-ohm load of the amplifier. In order to avoid making a very large number of calculations of voltage and power, you have constructed this graph. Now you can obtain the voltage and power for each value of current without having to work out each solution with pencil and paper.

The dashed lines on Fig. 36 show how the voltage and power for a current of .56 ampere would be read from the graph. Starting at .56 (point A) on the horizontal scale, trace upward to the intersection with the power curve (point B). Then trace over to the vertical scale and read 23 watts at point C. The .56 line intersects the voltage line at D. Tracing over to the vertical scale from D gives 42 volts at point E. The same graph could be used to determine the current for a specific power. You would simply reverse the procedure and start at the required power on the vertical scale. Then trace over to the power curve and down to the horizontal scale to read current.

It actually takes longer to tell how to read values from a graph than it takes to do it. The dashed lines which were drawn on Fig. 36 are not necessary in practice. They were used here only to demonstrate the procedure. With a little practice you will find that you can do the reading right at the curve without tracing to the scales. Try to determine the voltage drop and the power dissipation for the following currents: .72, .23, .07, and .48. What current is necessary for 60 watts, 36 watts, 7 watts, and 53 watts? Remember when reading the scale of a graph that, since an estimate is involved, all the rules for significant figures apply. You can check your readings by using the formulas to calculate the values.

Slope. One look at a graph can tell you a great deal about the way the dependent variable changes with changes in the independent variable. You have only to glance at Fig. 36 to know that voltage drop and power dissipation do not change in the same way with changes in current. The graph of voltage against current is a straight line. The increase in voltage for a given increase in current is the same at every point on the line. An increase of .1 ampere always produces an increase of 7.5 volts; an increase of .2 ampere always produces an increase of 15 volts. These relationships hold true no matter what value the current has at the start.

A special name is given to the rate at which the dependent variable changes with changes in the independent variable. This rate of change is called the slope. The slope is determined by dividing the span of the dependent variable over a section of the line by the span of the independent variable over the same section. Two examples of slope calculation are shown in Fig. 37. The two lines on this graph are plots of voltage against current for two different values of resistance. The slope of the line, R = 75 ohms, was calculated for the section between point A (.53, 40) and point B (.80, 60). The span of current is equal to the scale

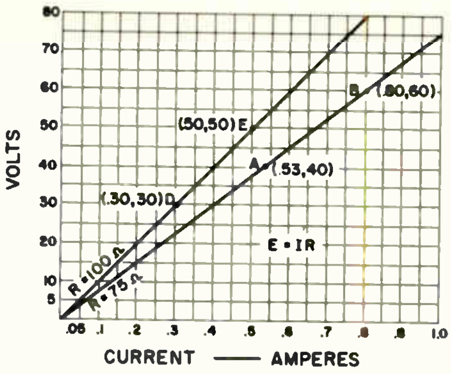


Fig. 37. Determining the slope of a line.

reading of B – A. The value of B (.80) minus the value of A (.53) is equal to .27 ampere. On the vertical scale, the reading of B is 60. We subtract the reading of A on the vertical scale (40) from B (60) to obtain the voltage span, which is 20. Dividing the voltage span by the current span gives 20 ÷ .27 = 75. The slope of the R = 75 ohms line is 75. The slope of the R = 100 ohms line is calculated between point D (.30, 30) and point E (.50, 50). The slope is (50 – 30) ÷ (.50 – .30) which works out to be 100.

You have undoubtedly already noticed that in both the examples of slope calculation the slope was numerically equal to the value of the resistance used in the formula which was plotted. Whenever the dependent variable is equal to the independent variable multiplied by a constant, the slope will always be equal to the constant. It is also true that the graph of the relationship will always be a straight line on rectilinear graph paper. Because the graph is a straight line, the relationship is said to be linear and the formula which expresses the relationship is called a linear equation.

The slope of a straight line is constant; that is, the slope is the same for all parts of the line. This is not true for all graphs. Unless the graph is a straight line on rectilinear paper, the slope will be different at different parts of the curve. In other words, the value of the slope depends on the value of the independent variable. Because the slope is continually changing, we must use a slightly different method to determine it. Fig. 38 shows how the slope of a curved line on a graph is obtained. First, it is necessary to draw a line tangent to the curve at the point at which the value of the slope is desired. (A tangent line is a line which touches the curve at only one point.) Three such tangent lines are shown on the curve. One is tangent at the point (.20, 3.0), another at (.40, 12), and the third at (.80, 48). The slope of the tangent line is determined by the same way as the slope of a straight line graph. The slope of the curve at the point where the tangent line touches it is the same as the slope of the line.

It is obvious that each of the three tangent lines has a different slope. It is also apparent that the slope is least when the current is least. As the current increases, the slope of the curve becomes greater. From a practical viewpoint this

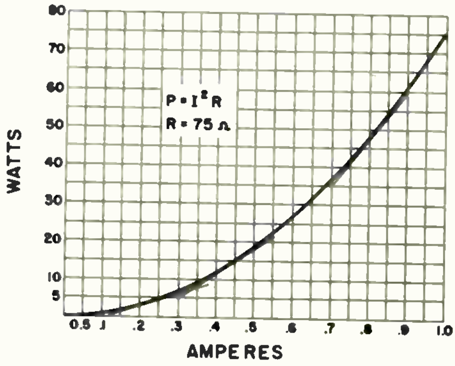


Fig. 38. Determining the slope of a nonlinear graph.

means that when the current is low, a small change in current results in only a small change in power, but when the current is large, a small change in current results in a large change in power. This type of curve will always result when the dependent variable is directly proportional to the square of the independent variable. Because the graph of the formula is not a straight line on rectilinear paper, the formula is said to be a nonlinear equation.

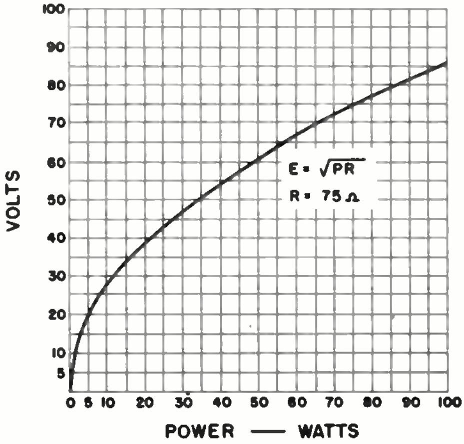


Fig. 39. Curve resulting when dependent variable is proportional to square root of independent variable.

Another common nonlinear curve results when the dependent variable is proportional to the square root of the independent variable. The curve of the formula $E = \sqrt{PR}$ for determining the voltage drop across a 75-ohm resistor for a given power dissipation is shown in Fig. 39. This curve has a high initial slope which decreases as the value of the independent variable becomes larger.

A third common nonlinear curve is shown in Fig. 40. This is the plot of current against resistance for a constant voltage drop.

The tangent to the curve at one point is also drawn in. Two points, A (2, 30) and B (8, 8) are marked on the tangent line and are used to determine the slope. In determining the span of the dependent variable, the value of the dependent variable at the point nearer the Y-Y′ axis is always subtracted from the value of the dependent variable at the farther point. Here we have

$$(8 - 30) \div (8 - 2) = \frac{-22}{6} = -3.66$$

This curve differs from the others you have studied in that it has a negative slope. The practical meaning of a negative slope is simply that the dependent variable becomes smaller as the independent variable becomes larger. The slope of this curve is greatest for small values of the independent variable, and least for high values. This curve shape and negative slope are characteristic of the graph of any equation in which the dependent variable is inversely proportional to the independent variable.

Each of the four types of formulas you are likely to use has its own characteristic graph curve. These curves show the way the dependent variable changes when the independent variable changes. The slope

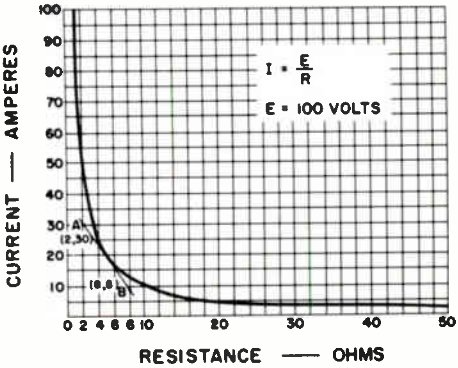


Fig. 40. Curve of a reciprocal relationship.

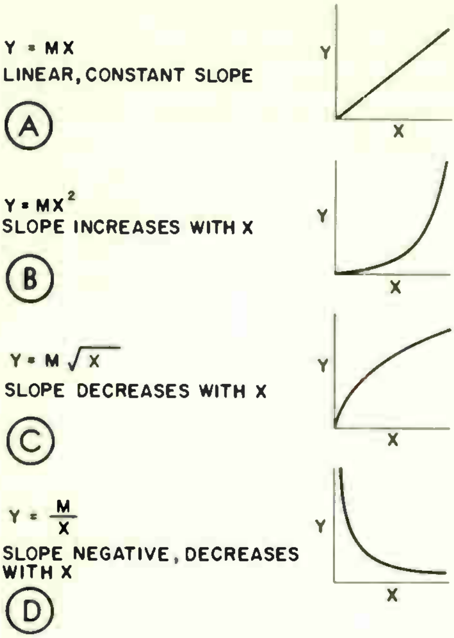


Fig. 41. Four common equations and their curves.

of the curves gives a numerical value to the rate of change. Fig. 41 summarizes the four types of equations and their curves. In the equations, X stands for the independent variable, Y for the dependent variable, and M for the factor of proportionality. Remember the general characteristics of the curve of each equation; they are a big help in visualizing the relationship expressed in a formula.

TYPES OF GRAPH PAPER

Common rectilinear graph paper is best for showing the relationship between variables. However, it is not always the easiest type to use. An accurate graph of some formulas can be obtained only by plotting a large number of points. It is difficult to read values from a curve when the curve is nearly parallel to either the horizontal or vertical grid lines. The uncertainty of readings near the low end of either scale is much greater than the uncertainty near the high end.

The plotting and reading of graphs can be made much easier by using graph paper which has special scales. There are many special types of graph paper for use in science, engineering and business. Three of these types are common in electronics.

Logarithmic. Most of the disadvantages of rectilinear paper can be overcome by plotting the logarithms of the variables instead of the variables themselves. To avoid having to look up the logarithms of every number, a special type of graph paper is used. The scales on this paper are laid out so that the distance of each number from the lower left corner is proportional to the logarithm of the number. Fig. 42 shows rectilinear and logarithmic scales side by side for comparison. The numbers on the rectilinear scale are ten times the logarithm of the numbers opposite them on the logarithmic scale. Notice in particular that there is no "0" on the logarithmic scale. There is no logarithm for zero.

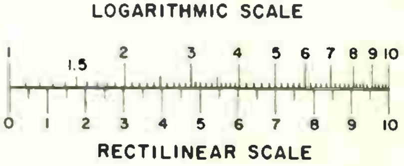


Fig. 42. Comparison of linear and logarithmic scales.

In order to extend the scale from 10 to 100, it is necessary only to repeat the 1 to 10 scale to the right of the 10. For numbers less than 1, it would be necessary to add additional 1 to 10 scales to the left of 1. Each complete 1 to 10 scale along an axis is called a cycle. Logarithmic graph paper is described by the

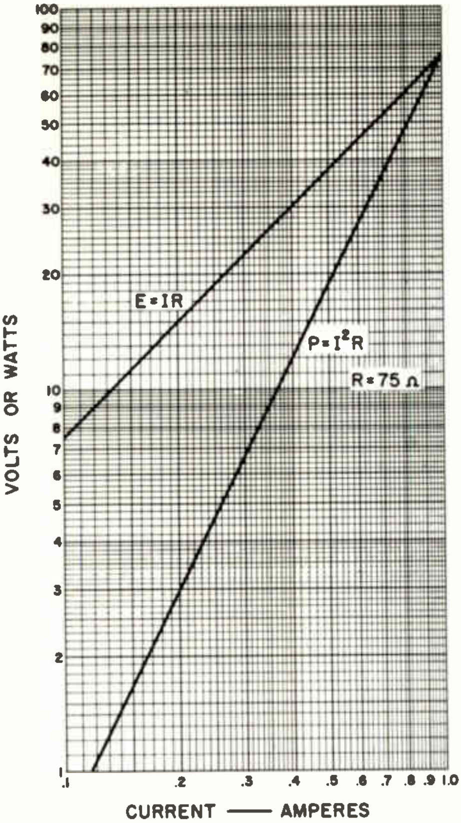


Fig. 43. Power against current and voltage against current plotted on logarithmic paper.

number of cycles along the horizontal and vertical scales. The chart on which Fig. 43 is drawn is called a "1 X 2 cycle."

One big advantage of logarithmic graph paper is that the uncertainty in reading numbers from the scale is the same at both ends of a cycle. The low end of the cycle can be read to three significant figures; the upper end of the cycle can be read to two significant figures. In both cases the uncertainty is about 1 part in 100. This is very important when a graph is used as an aid to computation.

Another advantage of logarithmic scales is shown in Fig. 43. The two lines on this graph are plots of the same relationships that gave one straight line and one curved line in Fig. 36. Both the voltage and the power plots are straight lines on this type of paper. In fact, all four of the typical equations in Fig. 41 are straight lines when plotted on logarithmic paper. This greatly simplifies the work of plotting. No more than three points need be calculated. (Actually two points are enough; the third is just a check.)

Although it is much easier to plot and read values from graphs on logarithmic paper, these plots have two big disadvantages. They do not show the exact manner in which changes in one variable affect the value of the other variable. Furthermore, you cannot determine the slope except in the case of the linear equation ($y = mx$).

A second disadvantage is the fact that there is no zero on the scales. On the 1 X 2 cycle paper used here, currents below .1 ampere, voltage drops below 7.5 volts, and powers below 1 watt do not show. If these lines had been plotted on 2 X 3 cycle paper, the lowest values would have been .01 ampere, .75 volt, and .1 watt. However, no matter how many cycles were used, zero would not appear.

Semilogarithmic Paper. Another type of special graph paper has a logarithmic scale on one axis and a linear scale on the other. The logarithmic scale may have from 1 to 5 cycles; the linear scale may have any convenient number of lines. The most common are 10 or 20 lines to the inch. One use for this type of paper is to obtain a straight line plot of an equation in which one variable is proportional to the logarithm of the other. Another use is where a large range of numbers must be covered on one scale. A linear scale would not show details on the low end, whereas a logarithmic scale would open up the

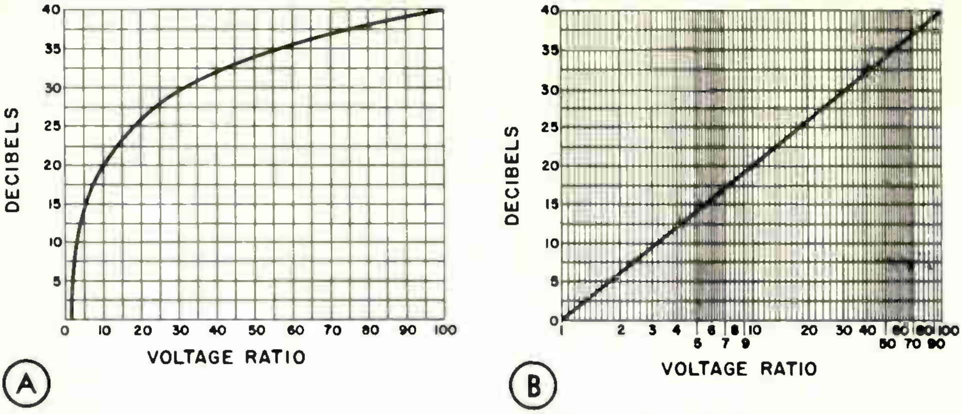


Fig. 44. Plots of voltage against decibels: (A) rectilinear; (B) semilogarithmic.

low end and make all parts equally readable.

Two plots of a logarithmic relationship between variables are shown in Fig. 44. Fig. 44A shows the plot of voltage ratio against decibels on rectilinear paper. At least 20 points must be calculated and marked to get a smooth plot. Even then the graph is very difficult to read below 15 on the voltage ratio scale. Fig. 44B shows the same relationship plotted on semilogarithmic paper. It can be drawn with only three calculations, and can be read with equal ease on all parts of the line.

Polar Graphs. A third type of special graph paper is laid out in polar coordinates. Points are located by means of radial lines marked in degrees and a series of circles with common centers which show the distance along the radials. This paper is used when you want to show the radiation patterns of antennas, loudspeakers, light sources, and other forms of energy transmitters. A polar plot is used for this type of graph since it gives a pattern of direction in space that is immediately apparent. Fig. 45 is an example of a graph plotted on polar coordinate paper. The graph shows the radiation pattern of an ideal quarter-wavelength antenna in free space. The distance of the points along the radials is proportional to the field strength in percent of the field strength in the direction of maximum radiation.

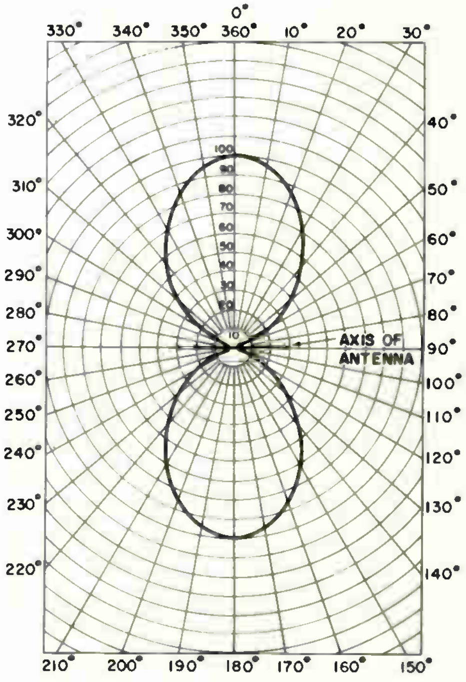


Fig. 45. Polar plot of antenna field strength.

SELF-TEST QUESTIONS

47. What is meant by the "slope" of a line?
48. How can the slope of a curved line be determined?
49. What is the difference between logarithmic graph paper and semilogarithmic graph paper?
50. What are some uses for polar graph paper in electronics?

Answers to Self-Test Questions

1. (a) 1.1×10^6
   (b) 7.2×10^3
   (c) 1.5×10^{-4}
   (d) 6.4×10^{-1}
2. (a) .000 000 000 326
   (b) 1,220,000
   (c) .00077
   (d) 9
3. 2.27×10^{-3}
4. 8.03×10^{-1}
5. 17.04

$$\begin{array}{r} 7.92 \\ 3.01 \\ 6.10 \\ 0.01 \\ \hline 17.04 \end{array}$$

6. Trigonometry is the study of the mathematical relationships that exist between the sides and angles of triangles.
7. 780 minutes; 46,800 seconds.
8. 360° contains 6.28 or 2π radians.
9. An acute angle is any angle that is less than 90°. An obtuse angle is an angle which is larger than 90°.
10. 58°.
11. The ***sine*** θ is the ratio of the side opposite the angle to the hypotenuse:

$$\frac{\text{opp}}{\text{hyp}}$$

The ***cosine*** θ is the ratio of the side adjacent to the angle to the hypotenuse:

$$\frac{\text{adj}}{\text{hyp}}$$

The ***tangent*** θ is the ratio of the opposide side to the adjacent side:

$$\frac{\text{opp}}{\text{adj}}$$

The ***cotangent*** θ is the ratio of the adjacent side to the opposite side:

$$\frac{\text{adj}}{\text{opp}}$$

The ***secant*** θ is the ratio of the hypotenuse to the adjacent side:

$$\frac{\text{hyp}}{\text{adj}}$$

The ***cosecant*** θ is the ratio of the hypotenuse to the opposite side:

$$\frac{\text{hyp}}{\text{opp}}$$

12. (a) .2250
    (b) .6947
    (c) .3443
    (d) .8387

13. (a) .0558
    (b) 1.2619
    (c) .9426
    (d) .2890
14. (a) 21°
    (b) 63°
    (c) 51°
    (d) 56°
15. (a) 54.5°
    (b) 31.3°
    (c) 9.1°
    (d) 48.2°
16. $(15 - j15)$ ohms;
    $21.2\ \underline{/-45^\circ}$ ohms
17. $(40 + j30)$ ohms;
    $50\ \underline{/36.9^\circ}$ ohms

$$Z = R_1 + R_2 + jXL_1 + jXL_2$$

$$- jXC_1 - jXC_2$$

$$Z = 40 + j55 - j25$$

$$Z = 40 + j30$$

$$\tan \theta = \frac{\text{opp}}{\text{adj}} = \frac{X}{R}$$

$$\tan \theta = \frac{30}{40} = .75$$

$$\theta = 36.9^\circ$$

$$\sin \theta = \frac{\text{opp}}{\text{hyp}}$$

$$\text{hyp} = \frac{\text{opp}}{\sin \theta} = \frac{30}{.5904} = 50 \text{ ohms}$$

18. (a) X is positive in the first and fourth quadrants. These are the quadrants to the right of the X axis.
    (b) Y is positive in the first and second quadrants. These are the quadrants above the X axis.
    (c) X and Y are both negative in the third quadrant. This is the quadrant beneath the X axis and to the left of the Y axis.
19. (a) The value of sin 150° is .5

$$\begin{aligned} \sin 150^\circ &= \sin (180^\circ - 150^\circ) \\ &= \sin 30^\circ \\ &= .5 \end{aligned}$$

    (b) The value of cos 150° is –.866

$$\begin{aligned} \cos 150^\circ &= -\cos (180^\circ - 150^\circ) \\ &= -\cos 30^\circ \\ &= -.866 \end{aligned}$$

20. (a) The value of tan 135° is –1

$$\begin{aligned} \tan 135^\circ &= - \tan (180^\circ - 135^\circ) \\ &= \tan 45^\circ \\ &= -1 \end{aligned}$$

    (b) The value of cot 225° is 1

$$\begin{aligned} \cot 225^\circ &= \cot (225^\circ - 180^\circ) \\ &= \cot 45^\circ \\ &= 1 \end{aligned}$$

The tangent is negative because it falls in the second quadrant, the cotangent is positive because it falls in the third quadrant.

21. (a) The value of sin –60° is –.866

$$\sin -60^\circ = -\sin 60^\circ$$
$$\sin 60^\circ = .866$$

Therefore

$$\sin -60^\circ = -.866$$

    (b) The value of cos –60° is .5

$$\cos -60^\circ = \cos 60^\circ$$
$$\cos 60^\circ = .5$$

The cosine is positive in the fourth quadrant.

22. (a) (4.85; 3.53)

$X = 6 \cos 36^\circ = 4.85$
$Y = 6 \sin 36^\circ = 3.53$

(b) (3.21; −3.83)

$X = 5 \cos -50^\circ = 3.21$
$Y = 5 \sin -50^\circ = -3.83$

23. (a) $12.1 \angle{-65.5^\circ}$ or $12.1 \angle{294.5^\circ}$

$$\tan \theta = \frac{-11}{5}$$

Therefore

$$\theta = -65.5^\circ$$

$$H = \frac{11}{\sin 65.5^\circ} = 12.1$$

(b) $9.23 \angle{229.4^\circ}$

$$\tan \theta = \frac{-7}{-6}$$

Therefore

$$\theta = (49.4^\circ + 180^\circ) = 229.4^\circ$$

$$H = \frac{7}{\sin 49.4^\circ} = 9.23$$

24. $18.6 \angle{+53.7}$ ohms

$$\tan \theta = \frac{\text{opp}}{\text{adj}} = \frac{+jX}{R} = \frac{15}{11} = 1.3636$$

$$\theta = +53.7^\circ$$

$$\sin \theta = \frac{\text{opp}}{\text{hyp}}$$

$$\text{hyp} = \frac{\text{opp}}{\sin \theta}$$

$$Z = \frac{+jX}{\sin \theta}$$

$$Z = \frac{15}{.8059}$$

$$= 18.6 \text{ ohms}$$

25. $8.1 \angle{-29.7^\circ}$ ohms

$$\tan \theta = \frac{\text{opp}}{\text{adj}} = \frac{-jX}{R} = \frac{-4}{7} = -.5714$$

$$\theta = -29.7^\circ$$

$$\sin \theta = \frac{\text{opp}}{\text{hyp}}$$

$$\text{hyp} = \frac{\text{opp}}{\sin \theta}$$

$$Z = \frac{-jX}{\sin \theta}$$

$$Z = \frac{4}{.4954}$$

$$= 8.1 \text{ ohms}$$

26. (5.8 − j6.9) ohms

$$\begin{aligned} Z &= Z (\cos \theta \pm j \sin \theta) \\ &= 9 (\cos 50^\circ - j \sin 50^\circ) \\ &= 9(.6428 - j.7660) \\ &= 5.8 - j6.9 \end{aligned}$$

27. $(10.2 + j6.4)$ ohms

$$\begin{aligned} Z &= Z(\cos\theta \pm j\sin\theta) \\ &= 12(\cos 32^\circ + j\sin 32^\circ) \\ &= 12(.8480 + j.5299) \\ &= 10.2 + j6.4 \end{aligned}$$

28. 171.9°
29. 97.4°
30. .272 radians
31. 80 ohms

$$\tan\theta = \frac{\text{opp}}{\text{adj}} = \frac{X}{R} = \frac{25}{76} = .3289$$

$$\theta = 18.2^\circ$$

$$\sin\theta = \frac{\text{opp}}{\text{hyp}}$$

$$\text{hyp} = \frac{\text{opp}}{\sin\theta}$$

$$Z = \frac{X}{\sin\theta}$$

$$Z = \frac{25}{\sin 18.2^\circ}$$

$$= \frac{25}{.3123} = 80 \text{ ohms}$$

32. 31.8 ohms

$$\sin\theta = \frac{\text{opp}}{\text{hyp}} = \frac{X}{Z}$$

$$X = \sin\theta Z$$

$$= \sin 45^\circ Z$$

$$= .7071\,(45)$$

$$= 31.8$$

33. −.2588
34. 63.8°
35. .811 or 81.1%

$$\begin{aligned} PF &= \cos\theta \\ \theta &= 35.8^\circ \\ PF &= \cos 35.8^\circ \\ &= .8110 \end{aligned}$$

36. 319 watts

$$P_a = E_T I = 393.8 \text{ watts}$$

$$PF = \frac{P}{P_a}$$

$$P = PF(P_a)$$

$$P = .811\,(393.8)$$

$$P = 319 \text{ watts}$$

37. $(4 + j3)$ ohms

$$\begin{aligned} Z &= Z(\cos\theta \pm j\sin\theta) \\ &= 5(\cos 36.9^\circ + j\sin 36.9^\circ) \\ &= 5(.7996 + j.6004) \\ &= 4 + j3 \end{aligned}$$

38. $R = 55$ ohms; $X_L = 437$ ohms. First find the dc resistance of the coil:

$$R = \frac{E}{I} = \frac{110 \text{ volts}}{2 \text{ amps}} = 55 \text{ ohms}$$

This means that a 55-ohm resistor is in series with a perfect coil. We can find the impedance of the coil when connected to ac by:

$$Z = \frac{E}{I} = \frac{110 \text{ volts}}{.25 \text{ amps}} = 440 \text{ ohms}$$

Now we know the impedance and the resistance in the circuit. This is equivalent to a right triangle in which the hypotenuse and the side adjacent to the angle θ are known. Now find angle θ:

$$\cos\theta = \frac{\text{adj}}{\text{hyp}} = \frac{R}{Z} = \frac{55}{440} = .1250$$

$$\theta = 82.8^\circ$$

$$\sin\theta = \frac{\text{opp}}{\text{hyp}} = \frac{X_L}{Z}$$

$$X_L = \sin\theta\,(Z)$$

$$= \sin 82.8^\circ\,(440)$$

$$= .9921\,(440)$$

$$= 437 \text{ ohms}$$

39. $28.2\,\underline{/45^\circ}$ ohms

$$Z_T = Z_1 + Z_2 + Z_3 + Z_4$$

$$= 3 - j6 + 10 + j19 + 2 - j7 + 5 + j14$$

$$= 20 - j13 + j33$$

$$= 20 + j20$$

$$\tan\theta = \frac{\text{opp}}{\text{adj}} = \frac{X}{R} = \frac{20}{20} = 1$$

$$\theta = 45^\circ$$

$$\sin\theta = \frac{\text{opp}}{\text{hyp}} = \frac{X}{Z}$$

$$Z = \frac{X}{\sin\theta}$$

$$Z = \frac{20}{.7071} = 28.2$$

40. 66.3 mfd

$$\text{PF} = \cos\theta$$
$$.707 = \cos\theta$$
$$\theta = 45^\circ$$

And, since a leading power factor is required, the angle must be −45°. Therefore, at 60 Hertz the X_C of the capacitor must be large enough to cancel the 20-ohm X_L and still have enough reactance left over to shift the current 45° ahead of the voltage. We have seen that a 45° shift occurs when $R = X$. Therefore, the X_C of the capacitor must be $R + X_L$ or 40 ohms. Thus,

$$C = \frac{.159}{fX_c} = \frac{.159}{60(40)} = \frac{.159}{2400} = .0000663$$

$$C = 66.3 \text{ mfd}$$

41. 553 watts. First find the current through Z_b.

$$I_b = \frac{E}{Z_b} = \frac{220}{71\,\underline{/-36^\circ}} = 3.1\,\underline{/36^\circ} \text{ amps}$$

Now find the apparent power of Z_b:

$$P_a = E_T I_b = 682 \text{ watts}$$

Since $P = P_a(\text{PF})$ and $\text{PF} = \cos\theta$, then:

$$P = P_a(\cos \theta)$$
$$P = 682(\cos 36^\circ)$$
$$P = 682(.809)$$
$$P = 553 \text{ watts}$$

42. $891\,\underline{/77.2^\circ}$ ohms. First find X_L and X_C.

$$X_L = 904 \text{ ohms}$$
$$X_C = 883 \text{ ohms}$$

Now find the overall impedance of the two parallel branches. To do this you must first find the impedance (Z_{RC}) of R_2 and C in series.

$$\tan \theta = \frac{\text{opp}}{\text{adj}} = \frac{XC}{R_2} = \frac{883}{250} = 3.5320$$

$$\theta = -74.2^\circ$$

$$\sin \theta = \frac{\text{opp}}{\text{hyp}}$$

$$\text{hyp} = \frac{\text{opp}}{\sin \theta}$$

$$Z_{RC} = \frac{X_C}{\sin 74.2^\circ} = \frac{883}{.9618} = 920$$

$$= 920\,\underline{/-74.2^\circ}$$

Next, assume a voltage across the two parallel branches to establish a current.

$$I_{RC} = \frac{100\,\underline{/0^\circ} \text{ volts (assumed)}}{920\,\underline{/-74.2^\circ} \text{ ohms}}$$

$$= .11\,\underline{/74.2^\circ} \text{ amps}$$

$$I_{R3} = \frac{100 \text{ volts}}{200 \text{ ohms}} = .5 \text{ amp}$$

Then convert the two currents to j-operator form so that they can be added.

$$I_{RC} = I_{RC}(\cos \theta + j \sin \theta)$$
$$I_{RC} = .11\,(.2720 + j.9618)$$
$$I_{RC} = .03 + j.106$$

And since the other branch contains only R_3:

$$I_{R3} = .50 + j0$$

Now add the two currents to find the total current:

$$I_T = I_{RC} + I_{R3}$$
$$= (.03 + j.106) + (.50 + j0)$$
$$I_T = .53 + j.106$$

Next convert I_T to polar form:

$$\tan \theta = \frac{\text{opp}}{\text{adj}} = \frac{.106}{.53} = .2000$$

$$\theta = 11.3^\circ$$

$$\sin \theta = \frac{\text{opp}}{\text{hyp}}$$

$$\text{hyp} = \frac{\text{opp}}{\sin \theta} = \frac{.106}{.1929} = .55$$

$$I_T = .55\,\underline{/11.3^\circ}$$

Thus the overall impedances of the parallel branches can now be found:

$$Z_p = \frac{E \text{ (assumed)}}{I_T} = \frac{100\,\underline{/0^\circ}}{.55\,\underline{/11.3^\circ}}$$

$$Z_p = 182\,\underline{/-11.3^\circ} \text{ ohms}$$

Then convert Z_p to j-operator form so that it can be added to the series impedance:

$Z_p = Z_p\ (\cos\theta - j\sin\theta)$
$Z_p = 182\ (.9805 - j.1929)$
$Z_p = 178 - j35$

Now add Z_p to the series impedance of R_1 and L_1.

$Z_T = 20 + j904 + 178 - j35$
$Z_T = 198 + j869$

Finally, convert to polar form:

$$\tan\theta = \frac{\text{opp}}{\text{adj}} = \frac{X}{R} = \frac{869}{198} = 4.3889$$

$$\theta = 77.2^\circ$$

$$\sin\theta = \frac{\text{opp}}{\text{hyp}}$$

$$\text{hyp} = \frac{\text{opp}}{\sin\theta}$$

$$Z = \frac{X}{\sin 77.2^\circ}$$

$$= \frac{869}{.9751}$$

$$= 891\underline{/77.2^\circ}$$

43. $75\underline{/-48^\circ}$ ohms. First find the reactances of the capacitors and coils.

$X_{C_1} = 67.7$ ohms

$X_{C_2} = 145$ ohms

$X_{L_1} = 62.8$ ohms

$X_{L_2} = 94.2$ ohms

$Z = 50 - j67.7 - j145$
$\quad + j62.8 + j94.2$

$Z = 50 - j55.7$ ohms

$$\tan = \frac{-55.7}{50} = -1.11$$

$$\theta = -48.0^\circ$$

$$\sin\theta = \frac{X}{Z}$$

$$Z = \frac{X}{\sin\theta}$$

$$Z = \frac{-55.7}{\sin -48^\circ}$$

$$Z = \frac{-55.7}{-.7431} = 75 \text{ ohms}$$

44. $1.33\underline{/48^\circ}$ amps

$$I = \frac{E}{Z}$$

$$I = \frac{100/0^\circ}{75\underline{/-48^\circ}}$$

$$I = 1.33\underline{/48^\circ} \text{ amps}$$

45. 89 watts.

$P = P_a\ (PF)$
$P_a = E_T I = 100 \times 1.33 = 133$ watts
$PF = \cos\theta = \cos 48^\circ = .6691$
$P = 133\ (.6691)$
$P = 89$ watts

46. 89 watts. R_1 is the only component which can dissipate power. Therefore, it dissipates the entire 89 watts.

You can arrive at this conclusion by:

$P = I^2 R = (1.33)^2 \ (50) = 89$ watts

47. The slope of a line is the rate at which the dependent variable changes with changes in the independent variable.
48. The slope of a curved line can be determined by drawing a line tangent to the curve at the point of interest and calculating the slope of the tangent line.
49. Both the horizontal and vertical scales are logarithmic on logarithmic graph paper. On the other hand, semilogarithmic paper has a logarithmic scale on one axis and a linear scale on the other.
50. Polar graph paper is useful for plotting the radiation patterns of antennas, loudspeakers, and light sources.

Lesson Questions

Be sure to number your Answer Sheet X206.

Place your Student Number on every Answer Sheet.

Most students want to know their grades as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of lessons before new ones can reach you.

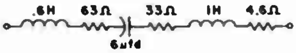
1. Give the sines of the following angles: 23°, -47.5°, 290°, 163°, 215°.

2. Convert $12 + j10.8$ to polar coordinates.

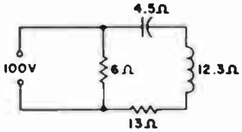
3. Convert $30\underline{/-50.5^\circ}$ to rectangular coordinates.

4. What are the power factors of circuits having the following impedances: $67.1\underline{/68^\circ}$; $123\underline{/-84^\circ}$; $.015\underline{/72^\circ}$; $1.49\underline{/60^\circ}$; $15.1 - j7.7$?

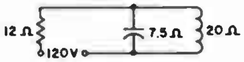
5. What is the impedance in polar coordinates at 60 Hertz of the circuit at the right?



6. What is the current through the circuit at the right? Give your answer in polar form.



7. What is the power dissipated in the circuit at the right?



8. Express as exponential numbers: 57 pf, 10 megohms, .16 microsecond, 26.7K ohms, 4503 kHz.

9. Solve the following problem and express your answer as an exponential number with the correct number of significant figures:

$$\frac{.0073(14.689 - 3.2)}{569} \times \frac{117 \times 9.64}{.00857}$$

10. Sketch graphs, as in Fig. 44, for capacitive reactance with capacity as the independent variable, and inductive reactance with inductance as the independent variable. Label the axes.

CONFIDENCE

Whatever project you undertake, *confidence* in yourself, and in your ability, will make the job easier.

By *confidence*, I do not mean "cockiness," and I most certainly do not refer to *fake confidence* which is simply "bluffing."

I'm speaking of the *confidence* which comes only from a thorough understanding of your work – and a genuine desire to do a good job.

This kind of *confidence* is felt by the people with whom you associate. It *causes them to have confidence in you* – to rely upon your judgment – and to entrust important work to your care.

Successful businesses – important jobs – are managed by men with *confidence* in their ability and desire to do a good job.

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