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ALLIED
BASIC ELECTRONICS

BASIC CIRCUITRY, FROM THE VACUUM TUBE TO ELECTRONIC CONTROL CIRCUITS, WITH EXPERIMENTS FOR CLASS USE

Based On The **knight-kit**®
12-In-1 ELECTRONIC LAB KIT

ALLIED RADIO

100 N. WESTERN AVENUE CHICAGO 80, ILLINOIS

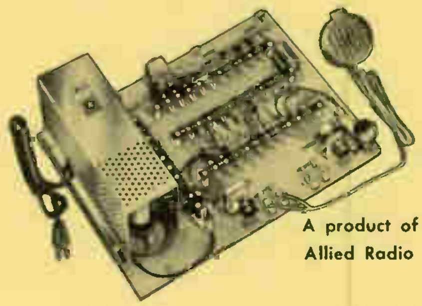
Foreword

This course of instruction has been prepared to answer the request of many teachers of science, physics, radio, electricity and industrial arts.

It is a step-by-step guide to the principles involved in electronic circuits for communications and control. In addition (and at this point it departs from the pattern of the usual textbook) it is built around a "packaged laboratory", the Knight-Kit 12-in-1 Electronic Lab Kit, that very simply demonstrates the circuits described in the text. This kit, which makes up any of 12 circuits, comes with a manual of assembly instructions which also describes the circuitry and the functions of the various components in each circuit.

"Basic Electronics" covers the theory of electronic circuitry and, in addition, contains experiments that can be performed with the Knight-Kit 12-in-1 Electronic Lab Kit. Only the minimum of equipment is required to do the experiments described.

It is assumed that the student has already learned the elements of electricity. The material covered in this book is suitable for introducing both secondary school and college students to basic electronics.


A product of
Allied Radio

THE KNIGHT-KIT 12-in-1 Electronic Lab Kit is an easy to use electronic laboratory kit, containing all parts necessary to set up each of 12 working circuits, as described in this book. Parts, after initial mounting on board, need not be removed to change circuits. Connections are made by soldering leads between terminals. Comes with fully illustrated construction and use manual. Available from Allied Radio.

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I. VACUUM TUBES

The vacuum tube is the core of modern electronics, radio and television. Without the tube, they would not have developed to their present state.

About seventy years ago Thomas Edison, in experiments with the incandescent lamp, found that when an additional element was placed in the lamp, a current could be drawn from the hot filament to the new element, called the plate (or anode). When the plate was connected to a negative voltage, no current would flow from the filament to the plate. However, when the plate was connected to a positive voltage, with respect to the filament, a small current could be measured in the external plate-to-filament circuit.

This effect, called the "Edison Effect," was considered a mystery until 1899, when J. J. Thompson explained the action as due to electrons given off by the heated filament. Two years later, a scientist by the name of Richardson advanced the theory that a force acting at the surface of the metal filament tends to keep its free electrons within the metal. Additional energy added to the electrons will cause them to leave the surface. In most vacuum tubes, this added energy is in the form of heat. Some special tubes use the energy in a beam of light, or the kinetic energy of a rapidly moving electron.

In 1896, J. A. Fleming found that the "Edison Effect" could be used in radio communications. He placed the filament, or cathode, and the plate, or anode, in an evacuated glass envelope and produced a vacuum tube. Since two electrodes are used in this type of tube, it is commonly called a "diode." The diode was used in early radios as a "detector" of radio frequency signals. It has found even greater use as a "rectifier" to supply direct current from alternating current sources.

About eight years after the development of the diode, Lee DeForest inserted a wire mesh grid between the cathode and plate. The action of this third electrode provided a simple means for controlling the amount of plate current. This grid is therefore known as the control grid. Since three electrodes are used, this tube is called a "triode." The effect of the triode was enormous, for before this, it was not possible to boost the amplitude of the signals in a radio. This was no longer an obstacle, for the greatest value of the triode was its ability to amplify. By means of this amplification, world-wide communication was established on a basis previously thought to be impossible.

The triode was a great step forward, but there were limitations to its use. To overcome these, another grid was added in the region between the control grid and the plate. It is called the "screen grid." This tube, the tetrode, was a much better performer than the triode, but its operation was quite critical, due to emission of electrons by the plate. This emission is caused by high velocity electrons travelling from the cathode. They "knock" electrons out of the plate when they strike it. To reduce this "secondary" emission, a third grid was added making a five-element tube, or "pentode." The third grid suppresses secondary emission, and hence, is called a "suppressor grid."

The development of improved radio receivers, demanded new tubes with special capabilities. To answer this demand, the practice of adding grids was again used, and soon, tubes were developed with four and five grids. Tubes with four grids, or six elements, are called "hexodes." The five-grid type is called a "pentagrid" tube.

The large number of individual tube types available today is often confusing to the beginner. It would seem impossible to remember the characteristics of all the various types; however, it is much easier than one may expect. Almost all of the types are variations of a few fundamental principles, and once these are mastered, the "impossible" seems rather easy.

In any vacuum tube, the entire operation is dependent upon a source of electrons within the tube. Various methods are used to produce emission of electrons. Thermionic emission and secondary emission are the most important. Photoelectric (light) emission is employed in TV camera tubes and in photocells. Field emission and radioactive disintegration are rarely used methods of obtaining electron emission in vacuum tubes.

Thermionic emission is named from the fact that heat is used to cause emission. When the cathode is heated, its free electrons tend to move faster, due to the increase in their energy. Those near the surface tend to leave the metal and go farther and farther away as the heat energy increases.

The sum total of these negative electron charges emitted by the cathode, that are in the space around the cathode, is referred to as "space charge." Remember that an electrostatic force acts between each and every electron, and also between each electron and the cathode. The electrons at the cathode surface push their way out into the space charge. As the cathode is brought up to its normal operating temperature, the number of electrons in the space charge gradually increases until it reaches a maximum value. At this point, just as many electrons will be emitted from the cathode as will be repelled back to the surface by the negative space charge.

Any method can be used to raise the temperature of the cathode to the point where emission occurs. The most practical method is to heat the cathode by electricity. The heat can be applied in one of two ways: directly, or indirectly. In the directly heated cathode, the emission takes place from the surface of the heated element itself. The indirectly heated cathode employs a separate heater, called a filament, which heats the cathode or emitting surface. Figure 1 shows the construction of this type of unit.

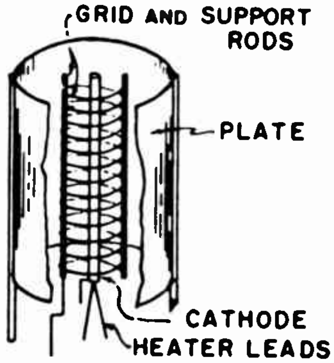


Fig. 1. **INDIRECTLY HEATED CATHODE CONSTRUCTION**

By using an anode (called a plate) in the tube we can attract electrons from the space charge and form a current that flows from cathode to plate. Referring to Figure 2, we see a simple diode circuit that will produce this type of current flow. The diode has an indirectly heated cathode which is connected to a battery for heater current. The plate is connected to the positive side of the "B" battery, and the cathode is connected to the negative side of this battery. The battery that provides the heater current is called the "A" battery; plate voltage is supplied by the "B" battery. We see that the "B" battery causes the plate to be positively charged with respect to the cathode. When electrons are emitted from the cathode, the positive charge on the plate attracts these electrons. The larger the positive plate voltage, the more electrons the plate will be able to attract from the cathode, and thus, the larger the plate current.

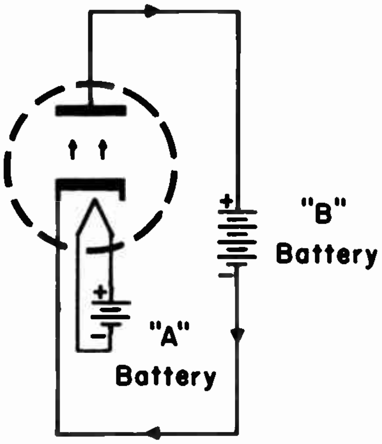


Fig. 2. **CURRENT FLOW IN A DIODE**

If we make a graph showing how the plate current will vary as we vary the plate voltage, it would look like the graph in Figure 3. When the plate voltage is zero, no current flows. As the voltage is increased, the current gradually begins to flow. The lower curved portion of the graph is referred to as the "square law" portion of the curve because in this region the current is proportional to the square of the voltage. Thus, if we were to double the voltage, the current would be increased four times. In the linear region of the curve, the current is directly proportional to the voltage. A voltage is finally reached which permits the plate to take all the emitted electrons. This condition is called saturation. Increasing the voltage beyond this point does not appreciably increase the current.

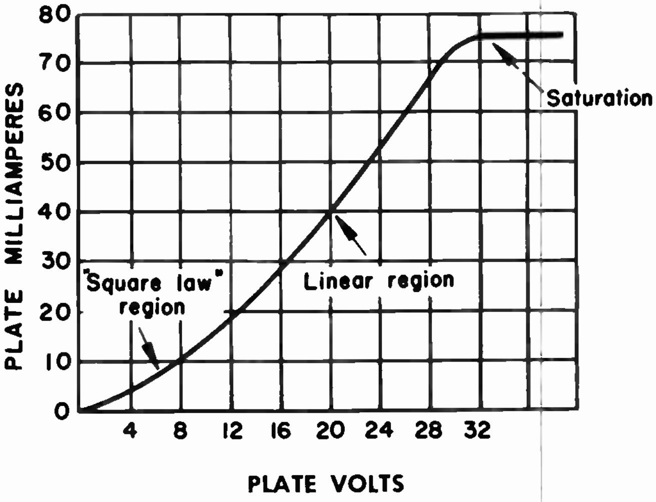


Fig. 3. **DIODE PLATE VOLTAGE — PLATE CURRENT CHARACTERISTICS**

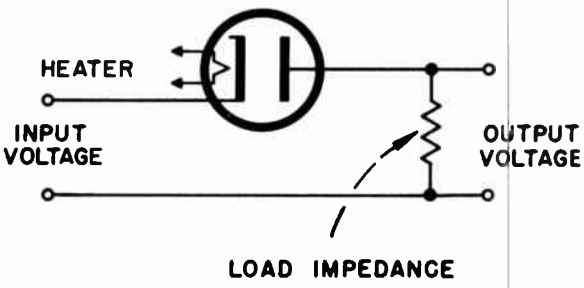


Fig. 4. **GENERAL TYPE OF DIODE CIRCUIT**

Figure 4 shows a common diode circuit. The diode is placed in series with a load impedance. Voltage is applied to the entire series circuit, and the output is obtained across the load. A typical application is in a rectifier circuit. Figure 5 shows a half-wave rectifier circuit. Note that the input voltage is obtained from the secondary of a transformer. The filament voltage is also supplied by this transformer. This provides great flexibility since proper selection of the transformer step-up or step-down ratio will insure correct operating voltage. The load impedance is the condenser-resistor combination between cathode and ground. If an AC voltage is applied to the plate of a diode, it only conducts during the positive portion of the cycle. This current, a pulsating DC, will flow through the resistor R and provide a DC voltage output. Capacitor C is used as a filter to smooth out the wide variations and provide a more constant DC output voltage.

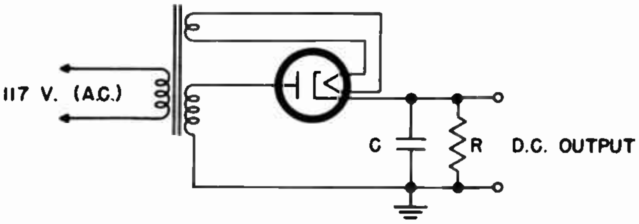


Fig. 5. EXAMPLE OF TYPICAL DIODE CIRCUIT

The device just described is a half-wave rectifier. The full-wave rectifier uses two diodes and is designed to conduct on both halves of a cycle. Another very common application of the diode is as a detector of A.M., F.M., and TV signals. In this application, it is again the ability to "rectify" the signal that permits the diode to extract the intelligence from the received signal.

Modern radio and TV receivers also use another type of rectifier element. Many materials have the ability to rectify. In the early days of radio, crystals such as galena and carborundum were employed in detector circuits. Copper oxide and other metallic rectifiers have been used in industrial equipment for many years. The most popular rectifier for receiver use today is the selenium rectifier. These are employed singly, as half-wave rectifiers, or in a two-section unit as a full-wave device. The full-wave rectifier employed in the Knight-Kit 12-in-1 Electronic Lab is a typical selenium circuit. This circuit is illustrated at the top of page 12 of the 12-in-1 manual. Inspect the full-wave selenium that comes with the 12-in-1 Electronic Lab. Note its construction and physical appearance.

You should now begin assembling the major kit components as per the instructions on pages 4-9 of the manual. Inspect all of the individual parts before you mount them on the chassis. Be sure you read the directions carefully.

We have already stated that the grid regulates the number of electrons that the plate can attract from the space charge. The grid is constructed so that electrons will pass right through its wire mesh. If the grid voltage is made negative, it repels the electrons in the space charge and reduces the plate current flow. The negative grid potential simply adds to the existing negative field of the space charge and repels the electrons near the cathode with greater force, thus reducing the number available to flow to the plate. This effect may be overcome, of course, by increasing the positive voltage applied to the plate. When the grid voltage is positive, its charge counteracts and reduces the negative space charge, thus making the plate voltage more effective and permitting more plate current to flow. If the grid is alternately made positive and negative it will cause a corresponding increase or decrease in the plate current.

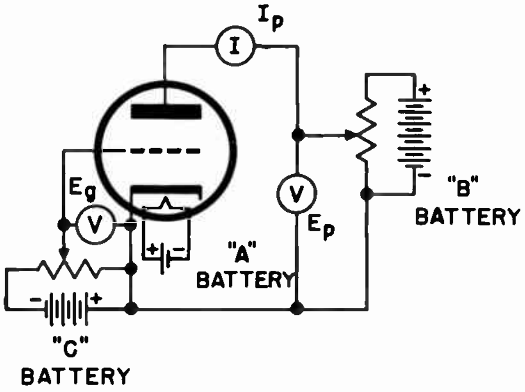


Fig. 6. USUAL MANNER OF APPLYING VOLTAGES TO A TRIODE

Figure 6 shows how voltages are usually applied to a triode. In most tubes the grid is operated so that it is negative with respect to the cathode, and the plate is positive with respect to the cathode. The "A-B-C" method is used to designate the various batteries. The "C" battery supplies the steady DC voltage for the grid.

In the diode, the plate current is determined by the plate voltage. The triode is constructed so that the potential of the grid has a much greater effect than the plate voltage upon the plate current. This is accomplished, mainly, by placing the grid much closer to the cathode than the plate. A relatively small grid voltage will produce an extremely strong field at the cathode surface while a substantial plate voltage will have less effect because it is so far away from the cathode.

The grid voltage may be made large enough in the negative direction so that the plate current is reduced to zero. The value of grid voltage that causes the plate current to cease flowing is called the "cut-off" voltage.

If instead of making the grid negative we make it positive, it will neutralize some of the space charge. The attracting power of the plate would then be effectively increased, and there would be an increase of plate current. In this case, the grid, being positive with respect to the cathode, also attracts some of the electrons from the space charge. Thus the tube draws "grid current." In applications where the available plate voltage is low (as in some 12-volt car radios) a positive grid provides greater current flow. The recently developed 12K5 tube utilizes a positive grid. This tube is used in the Knight-Kit 12-in-1 Electronic Lab. The 12K5 was developed to operate from plate voltages as low as 4 volts. Details of its operation are given on page 13 of the 12-in-1 manual. Study the construction of the 12K5 tube provided in the kit. Locate the heater, cathode, both grids and plate. Note the mechanical structure details.

The amplification factor or "mu" of a tube is a characteristic dependent upon its construction and electrode spacing. It indicates how much greater effect the grid voltage has compared with the plate voltage. Thus, a small control grid voltage can produce a large change in the output voltage across the plate load of tubes because it causes a large change in the current flowing through the load. The gain of an amplifying circuit, therefore, depends upon the "mu" of the tube used as well as the value of load resistance employed. In a comparison of different tubes, the type that has the highest "mu" will be capable of providing the largest gain when employed in an amplifier.

Another tube characteristic is the dynamic plate resistance. It is a measure of how much opposition the tube offers to the signal currents in the plate circuit.

The third important characteristic is the transconductance, or as it is sometimes called, the mutual conductance of the tube. This is a measure of the ability of the grid to produce changes in plate current and is a sort of grid-to-plate conductance. All of these tube characteristics are listed in tube manuals.

The tetrode tube was developed to overcome several of the shortcomings of the triode. The most important of these is the relatively large capacity between the grid and plate of the triode. These two electrodes in the tube act like two conductors separated by an insulator, thus making a capacitor. Unless this capacity is "neutralized" the triode cannot be used as an amplifier of high frequency radio signals. If not neutralized, energy is fed back from the plate circuit to the grid circuit through this capacity and causes oscillation. In this condition the circuit is useless as an ordinary amplifier. The tetrode uses an additional grid placed between the control-grid and plate to act as a shield or screen for the electrostatic lines of force between these two elements. This new grid, called the "screen-grid," reduces the net field between the plate and control grid, decreasing the feedback of energy through this path. Figure 7 shows how voltages are applied to the tetrode. The plate, grid, and cathode are connected in the same way as for the triode. The screen-grid is operated at a positive potential usually somewhat less than that of the plate.

The tetrode has a region of operation in which the high energy of the electrons striking the plate produces secondary emission which is collected by the screen-grid. This causes a dip in the plate current in this region and limits its operation. The pentode tube was developed to eliminate this condition.

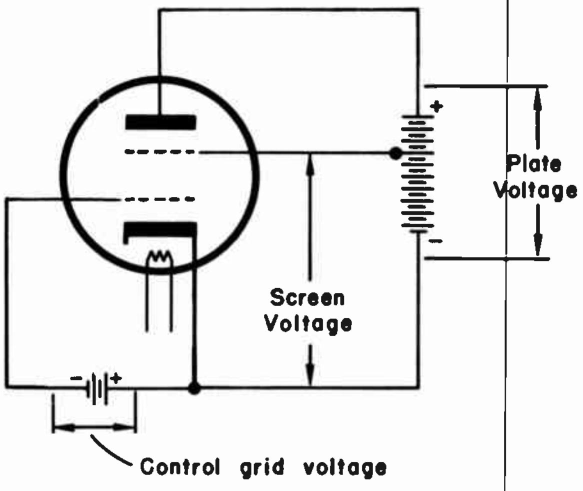


Fig. 7. VOLTAGE APPLICATION IN A TETRODE

The pentode employs a third grid placed between the screen and plate. Its major function is to suppress the secondary emission found to be troublesome in the tetrode. It is, therefore, called a "suppressor grid."

Consider again the cause of the dip in the tetrode current characteristic. It is due to secondary electrons produced at the plate. These electrons are collected by the screen instead of the plate. If an additional element is inserted between the plate and screen in such a manner that the flow of electrons from cathode to plate is not impaired, and if it is made negative with respect to the plate, secondary electrons emitted from the plate will be repelled by it and forced back to the plate instead of being collected by the screen. To insure that the suppressor be negative, it is generally connected directly to the cathode or to ground. In some tubes the suppressor to cathode connection is made within the tube.

The development of the pentode provided the field of electronics with a very versatile tube. Many modern broadcast, F.M. and TV receivers use pentodes for every stage of the receiver with the exception of the detector. This means that all of the amplification in the receiver may be achieved by pentodes. In addition to removing the dip in the tetrode characteristic, the pentode provides a higher gain than either the triode or the tetrode.

Other tube types have been developed for special functions. Beam power tubes, tuning indicators, convertors, multipurpose tubes, photocells and control tubes are now common in electronic circuitry. Certain of these types will be discussed in later chapters.

By now you are probably well on your way with the assembly and mounting of the components of the Knight-Kit Electronic Lab. Be sure you have carefully checked all connections and wiring. Your future experiments will use this unit so it will pay to be careful and accurate in its assembly.

II. RECTIFIERS AND POWER SUPPLIES

The radio receiver passed through a series of very interesting stages in its early development. Rectifying crystals, as mentioned in the first chapter, were used to detect the signals. These radios required the use of earphones because the lack of amplifying equipment prevented the use of loudspeakers. The vacuum tube amplifier greatly increased reception possibilities.

However, vacuum tubes required a source of operating energy such as batteries, which were expensive and troublesome. A power supply employing house current instead of batteries was urgently needed.

We have seen the result of applying DC voltage to the plates of tubes. What would be the result of applying an AC voltage (as in ordinary house wiring) to the plates of amplifier tubes in a radio? On the positive half cycle the voltage would provide a positive plate voltage and the tube would conduct. On the negative half cycle the voltage applied to the plates would be negative and no plate current would flow. Thus, the output of an amplifier tube with AC applied to its plate would be a series of half-wave current pulses occurring only during the positive half cycles. This would be reproduced by the earphones or a loudspeaker as a low frequency hum. The desired signal applied to the amplifier would be distorted by the hum to the point where it would not be recognizable.

No such problem exists with batteries. They supply a steady DC voltage that permits a constant flow of plate current. No disturbance of the signal could come from this. To obtain the same results when using an AC source, it is first necessary to change the AC into DC. This process is called rectification. Filtering by means of inductance and capacitance may then be used to smooth out the variations and thereby insure a constant DC plate voltage.

Alternating current continually changes its direction while direct current flows in only one direction. Thus, the first thing to be done is to remove the negative alternation from the AC to obtain current flow in one direction only. This will not be a steady flow of DC, however. The ability of many electronic devices to conduct current in only one direction may be used to obtain this varying or pulsating DC, as it is called. As mentioned in Chapter I, numerous devices and materials exhibit this property we call rectification. You have already wired the power supply section of the 12-in-1 Electronic Lab. Note that it uses a selenium rectifier. The wave forms obtained in various parts of this circuit are given and explained on page 12 of the 12-in-1 manual. They will be studied in Experiment No. 1.

Consider the vacuum tube as a rectifier. The cathode, when heated, emits electrons and a positive plate potential will attract these electrons. If plate and cathode are connected through a resistor outside of the tube, the electrons flow from the cathode to plate, through the resistor and back to the cathode completing the circuit. If the plate is negative with respect to cathode, the electrons cannot flow to it and the tube acts like an open circuit.

If we apply AC to a diode it will, therefore, pass current to the plate only during one-half of the time or for one-half of each cycle. The normal AC line voltage is 110 to 120 volts. Most vacuum tubes require plate voltages of other values to operate properly. We know that we may increase the line voltage with a step-up transformer. For lower voltages, a step-down transformer may be utilized. Such a transformer is employed in the power supply of the Knight-Kit 12-in-1 Electronic Lab. Since the 12K5 tube was designed to operate on low values of plate voltage the step-down unit provides the proper AC voltage input to insure the correct DC voltage output of the power supply. One of the procedures of Experiment No. 1 is to measure these transformer voltages.

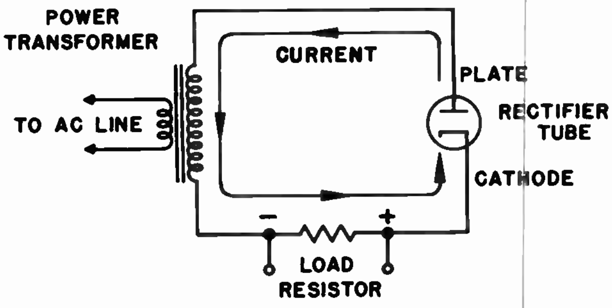


Fig. 8. HALF-WAVE RECTIFIER

To develop an output voltage, a resistor is inserted in the circuit and our rectifier appears as in Figure 8. When the plate is positive, current flows from cathode to plate and back to cathode through the external load circuit. This circuit is known as a half-wave rectifier since only one-half of the original AC wave appears at the output. The negative half cycles have, of course, been deleted. Rectifying crystals, copper oxide, selenium, etc., will provide a similar output.

The DC output voltage, thus obtained, is not steady and is, therefore, still not satisfactory for many applications. Filter circuits using inductors or capacitors or both, as well as resistors, are employed to smooth out the remaining fluctuations and provide a steady direct current output. For example, in the Knight-Kit 12-in-1 Electronic Lab power supply a resistor-capacitor filter is used. Experiment No. 1 will demonstrate this filtering action. Note again the various wave forms in the different sections of the supply as indicated in the diagram on page 12 of the Knight-Kit manual.

It is wasteful to lose half of the input wave. If we use a second diode to rectify the negative half cycle we would have a more efficient power supply. This diode would have to conduct during the half cycle when the first tube is not conducting. This can be obtained by connecting the diodes so that one diode plate becomes positive when the other one is negative and vice versa as the AC changes polarity. At any instant only one diode conducts. One-half cycle later when the polarities are reversed, the other diode conducts. We combine the two diode outputs by having both currents flow through the same load resistor. This new rectifier circuit is shown in Figure 9. Every half-cycle is rectified. This is appropriately called a full-wave rectifier. The full-wave rectifier provides greater output and requires less filtering than a half-wave unit.

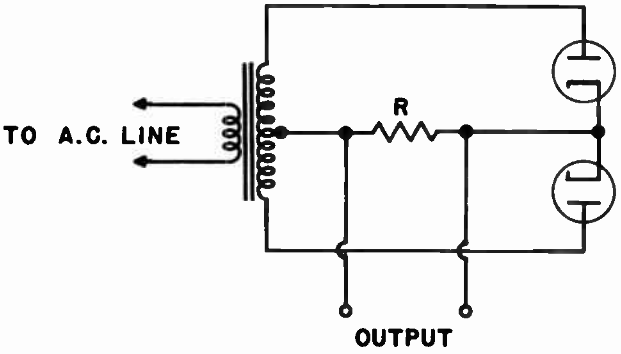


Fig. 9. **FULL-WAVE RECTIFIER**

As previously mentioned, the 12-in-1 Electronic Lab uses a typical full-wave selenium circuit in its power supply. It is similar to rectifier circuits employed in many modern TV and radio receivers. A condenser, C_2, acts as a filter to smooth out the fluctuations in the rectifier output. You are now ready to perform Experiment No. 1 and demonstrate many of the principles you studied in this chapter.

Experiment No. 1

Object:

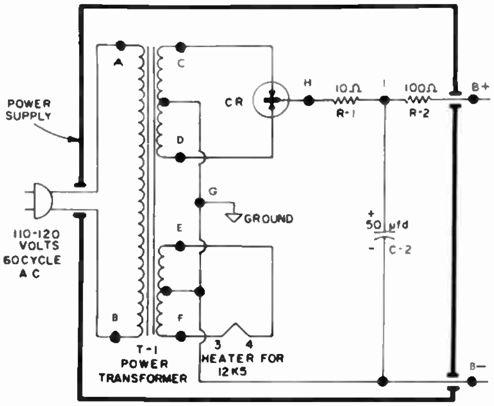
To study the principles of full-wave rectification.

Apparatus:

1. Assembled Knight-Kit 12-in-1 Electronic Lab
2. AC-DC voltmeter

Procedure:

1. Remove the four screws and nuts that hold the power supply cover to the kit proper. The power supply is now exposed and available for experimentation. Trace out the leads and components and compare with the diagram below.



12-in-1 Kit Power Supply

2. Using an AC voltmeter (0-150 range or higher) measure the input voltage to T-1 across points A-B. This can be measured at the AC outlet.
3. Still using the AC voltmeter measure the secondary voltages across terminals C-D, C-G, D-G, E-F, E-G and F-G. Go to a lower voltage scale if necessary.
4. Now employing a DC voltmeter determine the DC voltage output of the rectifier across terminals H-G. Use a 0-50 v scale.
5. Measure the DC voltage drops across R-1 (H-I) and R-2 (I and+).
6. Place the DC voltmeter across terminals + and G and read the supply output voltage.
7. Using an AC voltmeter read the AC output (ripple) voltage across terminals + and G. You will have to use a very low voltage scale for this measurement.
8. Repeat 7 after removing filter capacitor C-2 from the circuit. Compare the results with those of step 7.
9. Replace C-2 and repeat 7 with R-1 shorted. Compare the results with those of steps 7 and 8.
10. Repeat 7 with R-2 shorted. Explain the result.

III. AMPLIFIERS

Audio Amplifiers:

An amplifier is a device that "enlarges" or "amplifies" weak electrical signals so they can make a speaker or headphone operate.

An audio amplifier amplifies electrical signals of audible frequency. Before it can do its job we must first change the mechanical sound vibrations into electrical voltages. The microphone is used for this purpose. The operation of the carbon microphone is explained on page 12 of the Knight-Kit 12-in-1 manual. This type of microphone will be used in many of the experiments you will perform. Another common type of microphone is the moving coil microphone. Sound waves strike a diaphragm coil which then moves back and forth and cuts the lines of force of a strong permanent magnet. As the magnetic lines are cut, small currents are set up in the coil. These currents have the same frequency as the original sound waves. These weak currents may be introduced into the audio amplifier and amplified many times. To obtain sound waves again we use headphones and loudspeaker. They are constructed somewhat like the microphone but provide the reverse action, converting electrical energy into sound. Headphone operation is explained on page 13 of the 12-in-1 Knight-Kit manual.

When using a loudspeaker the strongly amplified signal currents are fed into a coil known as the voice coil. The voice coil is attracted or repelled by a permanent magnetic field depending, of course, on the polarity of its own field. As the coil moves an attached cone moves with it, setting up sound vibrations in the air. Note that this action is almost the reverse of that in the moving coil microphone.

Audio frequencies range from approximately sixteen cycles per second, such as would be produced by an automobile engine—up to 16,000 cycles, such as are developed by various whistles. Our ears cannot hear higher frequencies. For example, silent dog whistles produce a 20,000 cycle note, inaudible to us but easily heard by the dog. Below 16 cycles per second, we can feel vibrations, but cannot hear them.

The frequency range of an audio amplifier depends upon the use to which it will be put: telephone amplifiers, 125 to 3,500 cycles; AM receiver amplifiers, 90 to 5,000 cycles; phonograph amplifiers, 60 to 8,000 cycles; motion picture sound amplifiers, 16 to 8,500 cycles; and FM and TV sound, 20 to 15,000 cycles. These are the minimum frequency ranges the audio amplifier must handle to faithfully reproduce the sound involved.

Amplifiers may be classified according to the frequencies they amplify. Thus we have audio, radio and intermediate frequency amplifiers as well as DC amplifiers. A typical audio amplifier is illustrated diagrammatically on page 11 of the Knight-Kit 12-in-1 Electronic Lab manual. This amplifier is the subject of Experiment No. 2. It will be used to verify many of the basic amplifier principles.

There are two ways of classifying amplifiers; first, according to their use and, second, by their DC grid voltage or bias.

Thus, in terms of use, we have either voltage or power amplification. In the first case, we use the amplifier to increase the grid input voltage to a much larger value. In the second, the voltage on the grid produces power in a load in the plate circuit, such as for a loudspeaker. Generally, the tubes used for power amplification differ appreciably from those used in voltage amplification with respect to the mu (high for voltage amplifiers, low for power amplifiers) and with respect to plate current (high for power amplifiers, low for voltage amplifiers).

In the second method of classification, amplifiers are called "Class A," "Class B," "Class AB" or "Class C," depending on how much DC voltage is applied to the control grid. In Class A operation the bias is adjusted so that plate current always flows regardless of signal input grid voltage. Thus the net grid voltage never reaches cut-off value. With Class AB operation the grid voltage does reach cutoff and the plate current reaches zero for at least one part of the input cycle. Amplifiers operating as Class B devices use cutoff bias. Thus the tube normally operates at cutoff. This means that plate current can only flow when the polarity of the input signal voltage is positive. This reduces the negative grid voltage from cutoff and permits plate current flow. Negative inputs will make the grid more negative than cutoff and will still prevent plate current flow. In Class C amplifiers, the grid bias is normally more negative than cutoff. This means that only positive input signals of sufficient amplitude will cause plate current flow. The input voltage must be sufficiently large to overcome the negative bias. Class C amplifiers are not employed in audio amplification since they produce considerable distortion.

Let us consider again what we mean by amplification. To amplify means to make larger. In the case of voltage amplifiers, it means to make a voltage larger. That is, if one volt is placed on the grid, and we obtain twenty volts in the output, then we have increased the grid signal to twenty volts, or amplified it twenty times. Amplification is simply defined as the output voltage divided by the input voltage. If the input voltage were two volts, and the output 30, then the amplification would be 30 divided by 2, or 15.

How does amplification take place? Refer to Figure 10. Consider the moment when the sine wave input to the grid is at its maximum positive value (point A). At this moment, the plate current is greatest. This current, flowing through the resistance R in the plate circuit, causes a drop across it which is larger than the input grid voltage. The point on the plate waveform corresponding to this condition is B. Similarly, when the grid voltage is at point C, its most negative value, very little plate current flows, reducing the drop across R and causing the voltage on the plate to be higher (point D on the plate waveform). Notice that for a 5 volt signal on the grid, we now have a 50 volt signal on the plate. This represents an amplification of 10. Thus, amplification occurs because a small change in grid voltage causes a relatively large change in plate current. This, in turn, produces a large change in the voltage drop across the load resistance in the plate circuit. Since this drop represents the output voltage, and since it is much larger than the input grid voltage, we have a gain in voltage. Another way of showing amplification is by means of a characteristic curve of a tube. Refer to Figure 11. Suppose that the grid bias is adjusted to minus 40 volts. If an AC signal voltage of 20 volts peak is impressed on the grid, then the net grid voltage will vary from a maximum value of minus 20 volts to a minimum value of minus 60 volts. Without the signal on the grid, the plate current was steady at a value of 10 milliamperes. When the grid voltage is minus 20 volts (at the maximum positive input peak), the plate current rises to a value of 15 milliamperes, and when the grid voltage is minus 60 volts, the plate current is 5 milliamperes. If the load resistance R in the plate circuit is 10,000 ohms, then the voltage across the resistance when the plate current was maximum (15 milliamperes) is:

.015 x 10,000 or 150 volts.

When the plate current is 10 milliamperes, the voltage is:

.010 x 10,000 or 100 volts.

When the plate current is 5 milliamperes, the voltage is:

.005 x 10,000 or 50 volts.

We can readily see that for a peak grid voltage change of 20 volts, we have obtained a peak plate voltage change of 50 volts or a gain of two and one half. Note that the plate voltage varies above and below its average value of 100 volts.

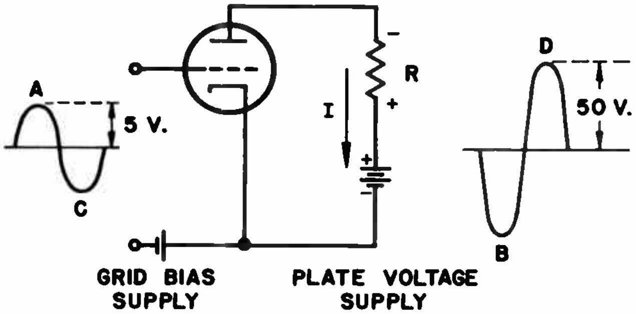


Fig. 10. HOW AMPLIFICATION TAKES PLACE

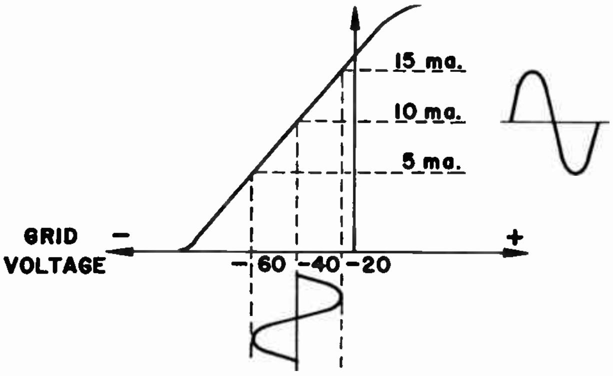


Fig. 11. PLATE CURRENT

The amount of amplification depends on three factors:

1. The mu or amplification factor of the tube.
2. The plate resistance of the tube (Rp).
3. The amount of load resistance in the plate circuit.

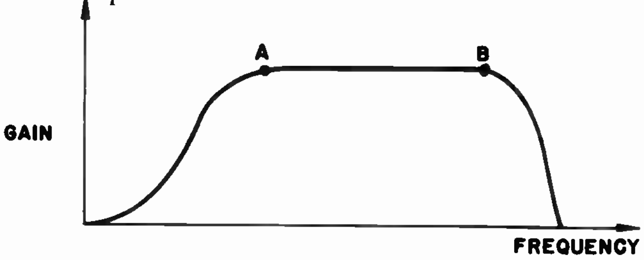


Fig. 12. GAIN vs. FREQUENCY CHARACTERISTICS

The most important and most often used characteristic of amplifiers is the "gain vs. frequency" characteristic illustrated in Figure 12. Notice that at the low frequency end of the characteristic, the gain falls off starting at point A. Similarly, at point B on the high frequency end, the gain again drops. In order to determine the reasons for this behavior, it is necessary to consider the complete circuit of an amplifier, Figure 13. The purpose of C_C is the total capacitance that shunts the circuit and consists of the plate to cathode capacitance of the tube, the grid to cathode capacitance of the next tube, and any stray wiring capacitance which exists in the cir-

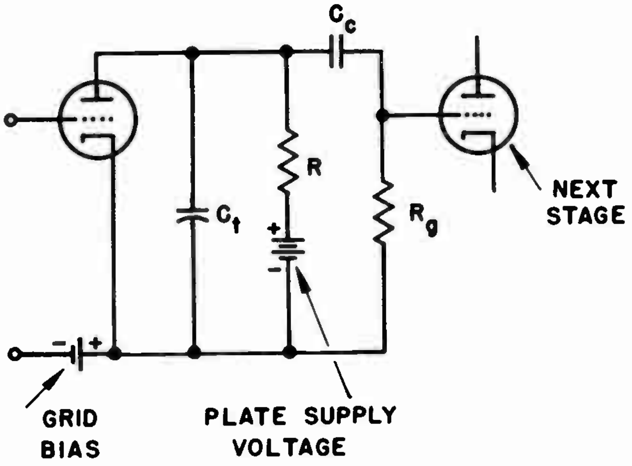


Fig. 13. ACTUAL A.F. TRIODE VOLTAGE AMPLIFIER

cuit. The effects of these circuit components on the frequency characteristics of the amplifier can be understood by considering the circuit under two different conditions: at low frequencies and at high frequencies. In the low frequency case, the reactance of Ct is so high that it is negligible in comparison with R which shunts it. As frequency decreases, the reactance of Cc increases and the voltage across it increases. Under these conditions, there will be less voltage across Rg resulting in a reduction in gain. The action of Cc in causing a gain reduction at low frequencies can also be explained by considering Cc and Rg as a voltage divider. Since the total voltage output of the amplifier stage is impressed across Rg and Cc in series, it is apparent that when the reactance of Cc becomes large enough, a loss of voltage will result. This, of course, occurs at low frequencies.

At high audio frequencies, the reactance of Cc is so small compared to the resistance of Rg in series with it, that it can be completely neglected. Rg and R are now directly in parallel with each other. Call the resulting resistance Rt. As frequency increases, the reactance of Ct becomes smaller. Much of the signal current is shunted through Ct, resulting in a loss. This accounts for the dropping off at higher audio frequencies. The range of frequencies in which there is no reduction of gain due to Cc and Ct is known as the MID FREQUENCY range.

Let us consider the method of biasing (providing grid bias for amplifiers). So far, only batteries between grid and cathode have been used in our circuits. It is much more convenient (no replacement necessary and more economical) to use a resistance in the cathode circuit for this purpose as in Figure 14. The plate current flowing upward through Rk into the cathode produces a voltage drop across Rk which causes the cathode to become positive with respect to ground. The grid, since no current flows through Rg, is at ground potential. Since the cathode is positive with respect to ground and the grid is at ground potential, the grid is NEGATIVE with respect to cathode. We have provided negative bias without the use of a bias battery. Since the plate current will vary when there is an AC signal on the grid, and since we desire a steady grid bias, it is necessary to bypass the cathode resistance (Rk) with the condenser Ck. The AC component flows through Ck and only the DC will flow through Rk. We, therefore, obtain a grid bias that does not vary. Ck is usually an electrolytic capacitor having a value of 8 to 10 microfarads or higher.

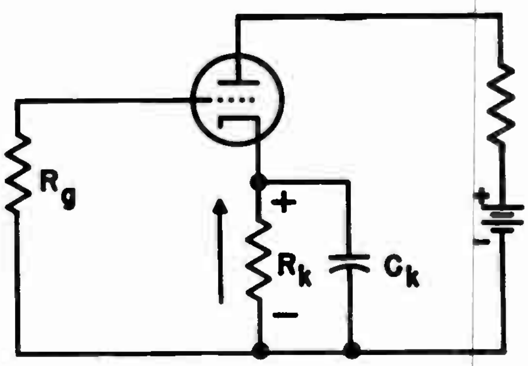


Fig. 14. HOW Rk PRODUCES GRID BIAS

Audio amplifiers are used to amplify the weak impulses from a "mike" in a radio station or in a public address system, to a useful level. They are used in receivers (AM, FM, and TV) to amplify the output of a detector stage to a high enough level to "drive" the power amplifier which provides energy to operate a speaker. They allow many of the deaf to hear, and also provide amplification for phonorecordings. The audio amplifier circuit of the Knight-Kit 12-in-1 Electronic Lab is a good example of an amplifier capable of performing these services. Your experiments will illustrate these principles and applications.

In most instances, the audio frequency voltage amplifier is used to drive (provide voltage for) an

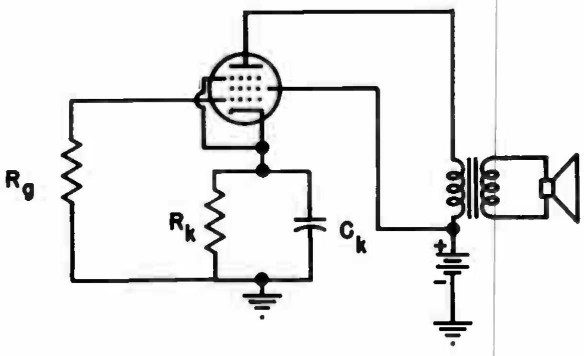


Fig. 15. SINGLE-ENDED PENTODE POWER AMPLIFIER

audio frequency power amplifier. Audio power amplifiers are divided roughly into two categories: single ended, and push-pull. Figure 15 is a drawing of a typical audio power amplifier. Notice that a transformer is used to connect the speaker to the output of the amplifier. This is a step-down transformer and provides the proper voltage for the voice coil.

The tubes that are used for audio frequency power amplifiers normally have a lower mu and lower Rp than those used for A.F. voltage amplification. Also, they normally draw much more plate current than ordinary A.F. voltage amplifiers.

The efficiency of Class A single ended power amplifiers is usually around 25%. It is governed by the ratio of the "load" impedance that the transformer presents to the plate resistance of the tube. Normally, distortion is the most important quantity besides output power, so that efficiency considerations are generally disregarded in this type of amplifier. Single tube power stages are nearly always operated "Class A" to minimize the distortion.

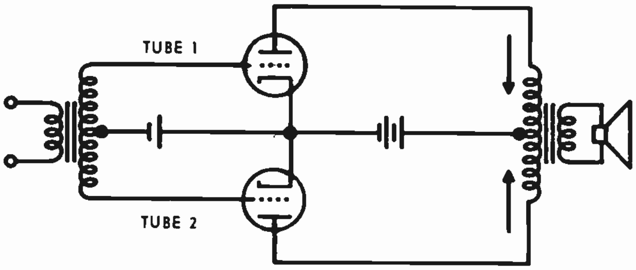


Fig. 16.

The push-pull audio power amplifier operates with the least distortion for a given amount of power output. It has many advantages over the single ended type of stage. Figure 16 is a diagram of a typical push-pull stage. The grids are fed simultaneously by a transformer. This provides signals on the two grids that are 180° out of phase with each other but, since the plate currents flow in opposite directions in the output transformer, their fields add in the output transformer to provide twice the output of a single-ended stage. The push-pull stage has the following advantages over the single-ended type:

1. Double the output power.
2. Much less distortion.
3. Output transformer operates better because *DC* current flows in opposite directions through each half thereby cancelling the DC magnetic field set up by the average plate current.
4. Cancels power supply hum on its plates.

Push-pull stages are used in public address systems, radio transmitters and, where high quality is desired, in audio amplifier sections of home receivers and phonographs, in high-fidelity amplifiers—anywhere that high-power, high quality audio is called for. Push-pull amplifiers are commonly operated as class AB or B in order to achieve higher efficiency. When in push-pull circuits these classes of amplifiers provide outputs of good fidelity.

A typical audio amplifier is shown in Figure 17. This is a three stage amplifier consisting of a pentode pre-amplifier fed by a microphone, a triode interstage amplifier and a transformer coupled push-pull output stage. Experiment No. 2 will demonstrate some amplifier fundamentals with the Knight-Kit Electronic Lab audio amplifier circuit.

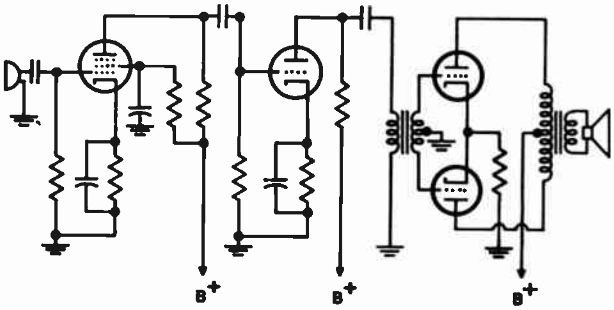


Fig. 17. TYPICAL AUDIO AMPLIFIER

Radio Frequency Amplifiers:

Radio frequency amplifiers (RF) are divided into classes: A, B, and C, depending on their bias voltage. Class A RF amplifiers are used exclusively in receiving circuits. Class B and C RF amplifiers are employed mainly in transmitter systems primarily as power amplifiers.

In receivers, RF amplification is generally considered to mean the voltage amplification of a signal at its incoming high frequency. The term is usually extended to refer to the amplification of all frequencies above about twenty thousand cycles per second. They function much in the same manner as do Class A audio amplifiers. Most RF amplifiers utilize tuned circuits. The tuned circuits restrict the band of frequencies over which they operate. These are known as TRF or tuned radio frequency amplifiers. RF amplification is valuable because a number of these stages may be used without appreciably increasing the background noise, thus providing large amplification. Background noise is a noise voltage produced by the operation of a vacuum tube and its associated circuits. It limits the gain obtainable from an RF amplifier stage. The tuned circuits also provide a greater output due to the rise of voltage at resonance.

A danger in using too many tuned RF stages results from the fact that each stage increases the selectivity of the overall system which may become so sharp that some important side frequencies will not be passed. This would result in a loss of some of the higher audio frequencies put out by the transmitter. Another disadvantage of too many RF stages is that as the signal energy increases in each successive stage, the field which it creates around the connecting wires and components reaches out to nearby circuits. This results in instability and oscillation in spite of the fact that modern tubes are designed to limit such an occurrence. Design techniques have been developed to reduce these effects. In subsequent sections you will study receiving systems using RF amplifiers. You will also experiment with a single tube radio receiver circuit which includes RF tuned amplification.

Experiment No. 2

Object:

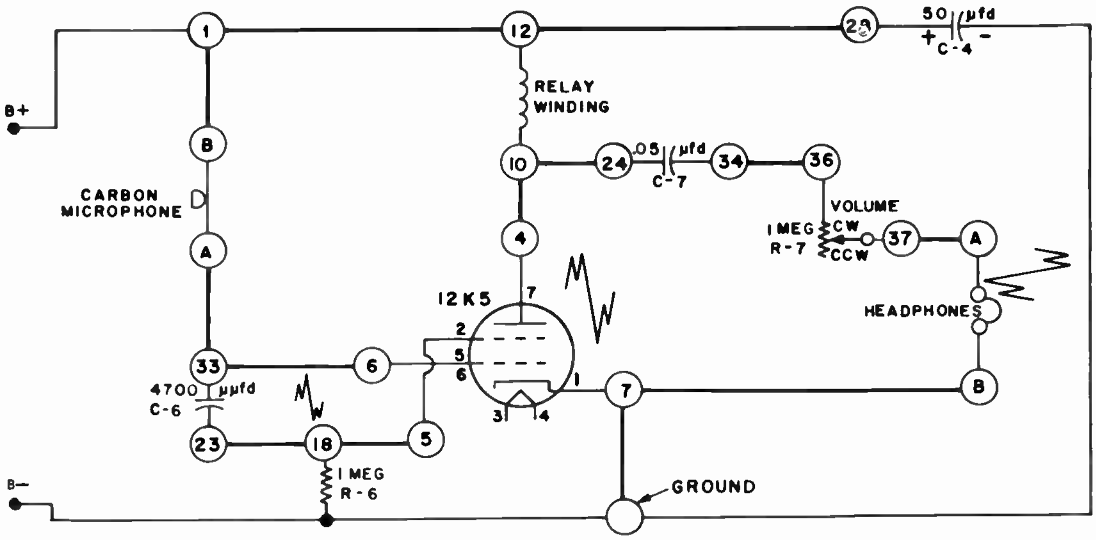
To study the fundamentals of vacuum tube amplifiers.

Apparatus:

1. Assembled Knight-Kit 12-in-1 Electronic Lab with carbon microphone and headphones.
2. DC Voltmeter.
3. Record player.

Procedure:

1. Wire audio amplifier as per instructions on page 10 of 12-in-1 manual.
2. Trace all leads and components and compare with the wiring diagram below.
3. Using your DC voltmeter determine the voltages of all the electrodes of the 12K5 tube, 7-1, 2-1, and 5-1.
4. Connect the carbon microphone and headphones as per the instructions on page 10 of the 12-in-1 manual. Talk into the microphone and check the amplification of the unit as well as the action of volume control R7.
5. Short terminals 12-10 and check the amplification. Explain the results.
6. Remove the short and disconnect the relay winding. Explain the action of the circuit.
7. Replace the relay winding and remove capacitor from the circuit. Note and explain the results.
8. As per the instructions on page 10 of the 12-in-1 manual, remove the carbon microphone and use a record player employing a crystal pickup as the input. Play a record and observe the action of the circuit. Measure all the D-C tube electrode voltages, 7-1, 2-1, and 5-1.
9. Remove capacitor C-6 from the circuit. Note and explain the results.
10. Replace C-6 and remove capacitor C-7 from the circuit. Note and explain the results.



Audio Amplifier

IV. DETECTORS AND RADIO RECEIVERS

The Detector and the Simple Receiver:

Two types of amplifiers are used in modern radio receivers. The RF amplifiers are located near the antenna and amplify the high or radio frequencies, while the audio amplifiers develop power for the sound reproducer. Between these two sets of amplifiers we find the detector, a device that separates the audio signal from the RF carrier. Suppose we consider the following question: Why not transmit the audio signal by itself and do away with RF amplifiers and detectors completely? To answer this question we must consider the theory of radio transmission.

The signal to be transmitted is amplified in the transmitter and then applied to the transmitting antenna. From here it is radiated into space to be picked up by the antennas of our radio receivers. To radiate efficiently, the transmitting antenna must be of a certain length, depending on the transmitter frequency. The lower the frequency the longer the antenna must be.

We know that audio frequencies range up to about 16,000 cycles per second. If audio signals were applied directly to a transmitting antenna, the antenna would have to be many miles long to give maximum radiation. Obviously, to build such an antenna would be highly impractical; but that is only half the problem. The antenna gives best results for a single frequency only, the one for which it has the correct length. The frequencies of speech or music are constantly changing and, if they were applied directly to the antenna, the strength of the radiated signal would be different for each frequency. Still another problem would arise: If all stations were to operate at audio frequencies, then all of the programs would be broadcast in the same frequency range. It would be impossible to tune one program in at the receiver and keep the others out.

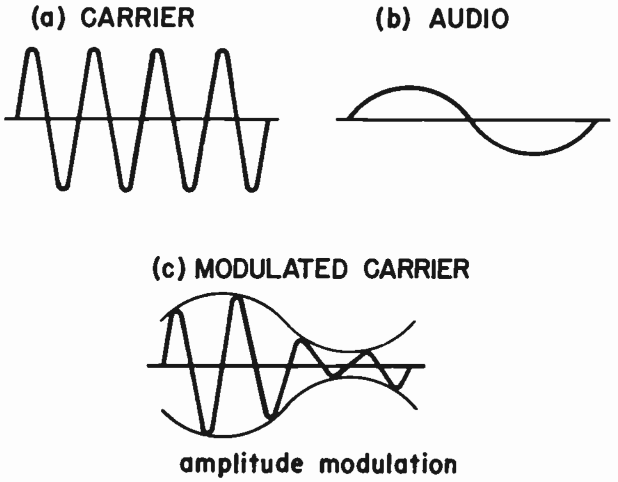


Fig. 18. (a) CARRIER (b) AUDIO (c) MODULATED CARRIER

All of these difficulties are avoided by radiating a signal of constant radio frequency from the transmitter and varying its amplitude in step with the audio signal. This process is known as amplitude modulation and is illustrated in Figure 18.

In the transmitter there is generated a radio frequency signal of constant amplitude. ("a" in the illustration). At some other place in the transmitter we find a microphone connected to a number of audio amplifiers. This produces the audio signal ("b" in the illustration). Before reaching the antenna, the two signals meet and the audio signal changes the shape (amplitude) of the RF signal in the manner shown at "C" in Figure 18. It appears as if the audio is riding atop the RF signal. The latter is called the carrier for this reason. Once the amplitude of the carrier is shaped according to audio variations, the carrier is referred to as the "modulated carrier."

Notice that the frequency of the carrier remains the same at all times. Only its amplitude changes and these variations are in step with the audio signal. At the receiving antenna we pick up this signal and it is fed into RF amplifiers. Once the signal is strong enough we have no more use for the RF carrier. Its frequency is so high that we cannot hear it. The part of the signal that we want is the amplitude variation of the carrier. This alone is a true representation of the original audio signal. The process by which this signal is obtained at the receiver is known as "demodulation" or "detection." The stage in which this process takes place is called the "detector."

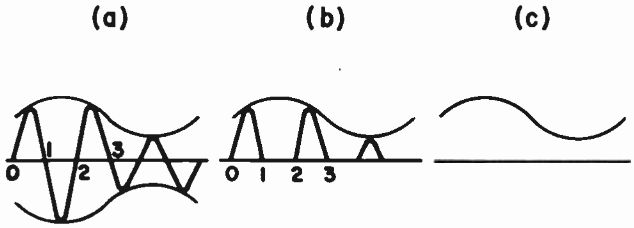


Fig. 19. DEMODULATION OF MODULATED CARRIER

To find out what functions the detector must perform, look at the modulated carrier, Figure 19. The audio variations are found above, as well as below, the reference line. To obtain a true reproduction of the audio we want only one set of these; therefore, the first duty we must assign to the detector is to cut the modulated carrier in half as at "b" in the illustration. The process by which this result is obtained is "rectification." Once the signal has been rectified we may get rid of the carrier frequency variations so that only the audio envelope is retained. This can be accomplished by feeding the rectified signal through a filter network similar to that used in the 12-in-1 power supply. The filter will bypass the high frequency but not the audio. The output from the detector appears as in "c" of the illustration.

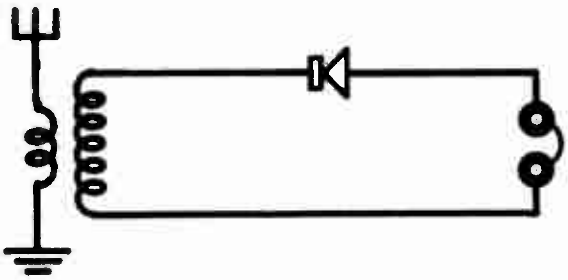


Fig. 20. SIMPLE CRYSTAL RECEIVER

Early radio receivers consisted only of an antenna, a tuner, a detector, and a reproducer. Such a simple receiver is shown in Figure 20. A receiver of this kind will provide good reception, but it in no way compares with modern equipment. This early model radio uses one of the oldest forms of detectors. This detector is made of carborundum or galena or of a similar material. Scientists discovered many years ago that certain crystals, notably the ones mentioned, have the unusual property of offering very low resistance to current flowing through them in one direction, while their resistance to current trying to pass in the opposite direction is almost infinitely large. What effect does this have on the radio receiver of Figure 20?

The modulated carrier is an AC signal. During the positive half cycle, current flows in one direction. Let us say the resistance of the detector to current flowing in this direction is small, thus, the signal will pass through the detector and reach the phones. During the next half cycle current again flows through the detector. The diaphragm inside the phones cannot follow these very rapid RF variations, but it is capable of responding faithfully to the variations in amplitude of the audio envelope. The response of the phones, therefore, will be at the audible rate.

Many detectors employed in modern radio receivers use diode tubes. A typical diode detector circuit is shown in Figure 21. An amplified, modulated carrier is transformer coupled from the output of the last RF amplifier (L_1), to the input of the detector (L_2). For every half cycle when the plate end of L_2 is positive with respect to the bottom end, the plate attracts electrons from the cathode. These electrons flow through L_2, the combination of R and C, and back to the cathode. When the half cycles of opposite polarity are applied, no plate current flows since the plate is then negative.

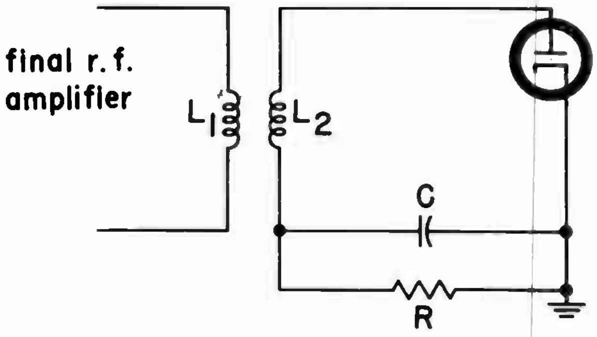


Fig. 21. DIODE DETECTOR

Triodes and pentodes can also be used as detectors. They provide amplification as well as detection in a single stage and are therefore useful in receivers where sensitivity is of utmost importance. The simple radio receiver circuit illustrated on page 15 of the Knight-Kit 12-in-1 Electronic Lab utilizes the 12K5 tube in a detector circuit. Its tuned input (G8, T-2) selects the proper input frequency which is applied to grid 2. The signal is amplified by the 12K5 and is then fed back to transformer T_2 to be amplified again. This process is called "regeneration" and provides a very large amplification. Since the 12K5 amplifies the positive half cycles more than the negative it also functions as a detector. This is a typical regenerative detector. You will perform experiments on this receiver.

The Tuned Radio Frequency Receiver (TRF)

The TRF Receiver occupied a place of prime importance in radio receiving systems some years ago. When designed properly, it provided good reception. The development of the super-heterodyne practically forced the TRF into obsolescence. Many of the circuits used in the TRF have counter-parts in the more modern receivers.

Since the signal voltages induced in an antenna are quite feeble, few receiving locations would be able to produce satisfactory results by feeding the antenna signal directly into a detector stage. Even then interfering signals would be numerous and the single selection circuit used with the detector would not be sufficient to keep the unwanted signals out. It takes an appreciable voltage to cause a detector to operate, so some means of amplifying the signal must be employed. This is accomplished by a Class A RF amplifier. Consider the task of selecting the one station we want to hear. Every transmitter in operation at a given moment generates a voltage in the receiving antenna. The antenna has electrical characteristics of its own which may give some of these signal voltages a greater advantage than others. Assume that one hundred stations are inducing an EMF in our antenna. We want to listen to just one. One of the purposes of RF amplification in this receiving system is to suppress 99 of the signals while allowing the desired one to come through amplified. The task of suppressing all but the desired signal is almost too great for a single RF stage. Two stages, or even three, may be necessary to bring about the desired selectivity. Each one of these stages must be carefully tuned to the frequency of the desired signal. Early receivers used separate tuning controls for each RF stage but such a system was very cumbersome to handle. As improvements were made, the condensers tuning the separate stages were mechanically linked together or ganged so that a single control could be used.

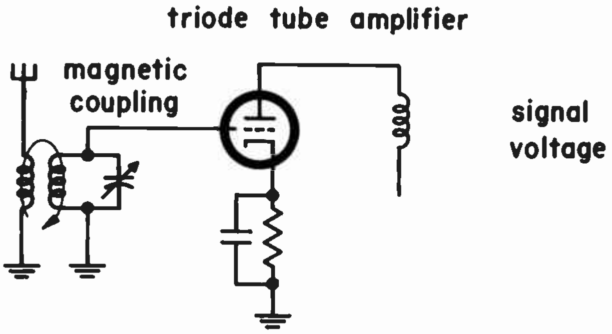


Fig. 22. T.R.F. STAGE

Figure 22 shows a triode TRF stage. The current flow through the primary sets up a magnetic field which cuts the turns of the secondary inducing a voltage. The secondary coil and tuning capacitor form an RF resonant circuit which can resonate at any frequency within the capacitance limits of the tuning capacitor. Assume that the tuning capacitor is adjusted so that the circuit resonates to 1,000 kilocycles. The reactance of the coil and capacitor are equal and in phase-opposition, so they will cancel. The 1,000 kilocycle signal will meet only the opposition due to the ohmic resistance in the circuit. Every other signal frequency will encounter reactance as well as resistance, for the reactances do not cancel for any frequency other than the resonant frequency. The RF resonant circuit therefore weeds out the undesired signals by building up impedance to them while allowing the desired signal to circulate with minimum opposition.

The voltage developed across the tuned circuit is applied to the input of the triode. The signal voltage from the tuned circuit is amplified and passed on to another circuit which may be a second RF amplifier or it could be a detector circuit.

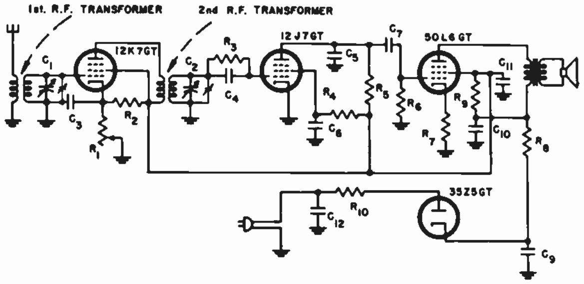


Fig. 23. CIRCUIT FOR 3-STAGE TRF RECEIVER

Figure 23 shows a circuit for a 3-stage TRF receiver. Various signals cut across the antenna inducing voltages which cause a flow of current through the antenna coil. The magnetic field set up about the primary cuts the secondary inducing a voltage. Note the small variable capacitor connected across the main tuning capacitor. This is called a "trimmer" capacitor. It is used to equalize any irregularities that may exist in the two tuned circuits. Even though the two sections of the gang tuning capacitor could be made identical in electrical characteristics, slight differences in the stray capacitance associated with each tuned circuit will require the use of some adjustable device for compensation. The coils may have slightly differing inductance values and the use of the trimmer makes it unnecessary to fabricate components to highly precise values. The tube is an RF pentode having a 12 volt heater. The heater circuit is not shown. Resistor R_1 provides grid bias for the RF stage and as this voltage is changed the gain of the stage is varied. The resistor thus acts as a volume control. Resistor R_2 serves as a bleeder resistance for the voltage delivered by the power supply. Capacitor C_3 filters the variable voltage of R_1. The variable plate current through the primary of the second RF transformer sets up a field cutting the secondary which is tuned by the other section of the gang capacitor. This section also has a trimmer. Capacitor C_4 in conjunction with resistor R_3 is a grid-leak grid-capacitor type detector circuit. Note that the cathode is grounded which places the grid at zero potential with no signal applied. Capacitor C_5 bypasses to ground any RF energy that might be transferred to the plate circuit of the detector. R_4 is a screen-grid dropping resistor and C_6 filters this supply. R_5 is the plate load resistor across which the audio voltage is developed. This voltage is coupled to the output stage through capacitor C_7 and is applied to the grid of the 50L6GT. Resistor R_6 completes the grid to cathode circuit of this tube. R_7 serves as its cathode biasing resistor. This resistor is not filtered, in order to improve the fidelity of the output. The output of the 50L6GT is transformer-coupled to the loudspeaker. Plate voltage supply is obtained from the 35Z5GT which is a half-wave high vacuum rectifier. B plus is taken from the cathode, and R_8, R_9, C_9, C_{10} and C_{11} serve as a resistance-capacitance filter for this supply. R_{10} is a protective resistor which limits the line current flow through the rectifier tube in case of a short circuit, while capacitor C_{12} filters RF interference which may be present in the line. The receiver is designed for broadcast-band reception.

Experiment No. 3

Object:

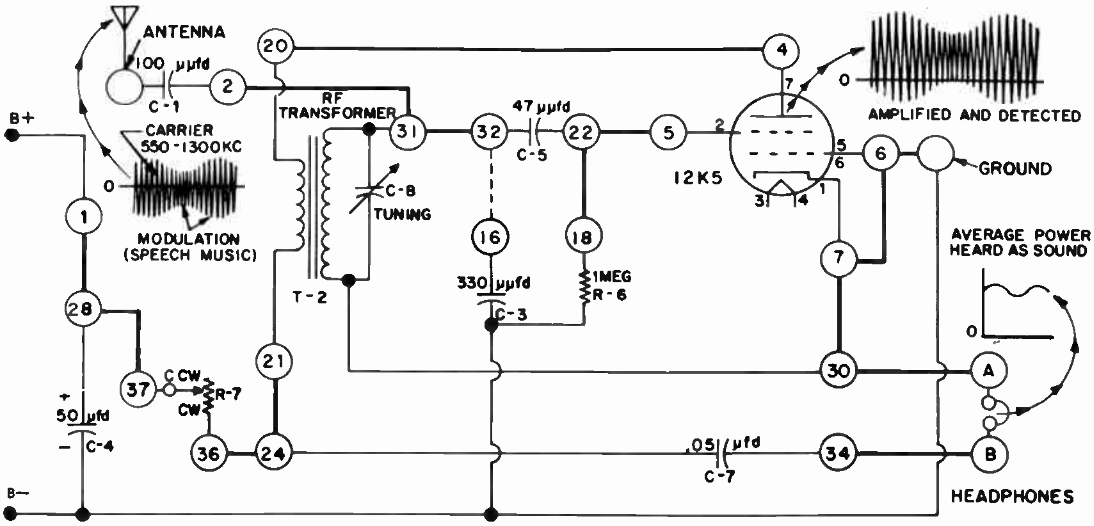
To study the action of a detector circuit and a single-stage radio receiver.

Apparatus:

1. Assembled Knight-Kit 12-in-1 Electronic Lab.
2. DC Voltmeter.

Procedure:

1. Wire the radio circuit of the 12-in-1 Kit as per the instructions on page 14 of the 12-in-1 Kit manual. Trace the circuit and compare with the wiring diagram below.
2. Tune in a number of stations at different frequencies across the bands from 550kc to 700kc and 700 kc to 1300 kc. Calibrate and check these frequencies against the settings of the tuning capacitor on another radio receiver. Note the effect of varying R-7.
3. Explain the action and results obtained when capacitor C-3 is removed.
4. Using the DC voltmeter determine all the electrode voltages, 7-1, 2-1, and 5-1.
5. Short capacitor C-5. Note and explain the results.
6. Remove the short across C-5 and remove resistor R-6. Note and explain the results.



Single-Stage Regenerative-Detector Radio Receiver

Experiment No. 4

Object:

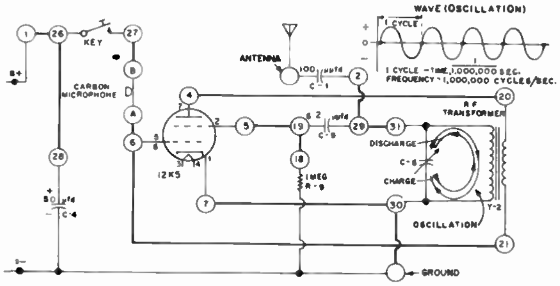
To study the principles of the vacuum tube oscillator and single-stage radio transmitter.

Apparatus:

1. Assembled Knight-Kit 12-in-1 Electronic Lab.
2. DC voltmeter.

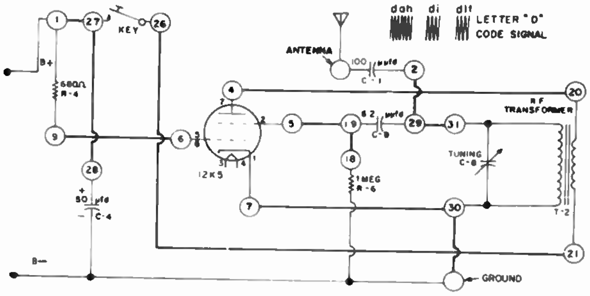
Procedure:

1. Wire the circuit of the Wireless Broadcaster as per the instructions on page 16 of the 12-in-1 Kit manual. Trace the circuit and compare with wiring diagram below.



Single-Stage Radio Transmitter

2. Place the unit into operation at a frequency determined by the setting of capacitor C-8. Receive the signals broadcast, on a standard broadcast band radio. Note the frequency. Repeat this procedure for various settings of the tuning capacitor C-8, noting for each the transmitter frequency.
3. Using the D.C. voltmeter measure all of the electrode voltages of the 12K5 tube; 7-1, 2-1 and 5-1.
4. Short R-6 and note the effect.
5. Short C-1 and note the effect.
6. Remove feedback capacitor C-9 and observe the effect.
7. Alternately open and close the key between terminals 26 and 27 to simulate radio telegraph signals. Explain the action.
8. Wire the Wireless Code Practice Oscillator as per the instructions of page 18 of the 12-in-1 manual. Trace the circuit and compare with the wiring diagram below. Compare this circuit with that of the Wireless Broadcaster. Operate the oscillator and check its output as received in a standard receiver.



Wireless Code Practice Oscillator

V. OSCILLATORS

The vacuum tube oscillator is employed in a wide variety of electronic devices and equipment. First, and most important, is its use as the heart of every transmitter, regardless of size or whether it be A.M., F.M., TV, short wave or amateur. Other examples are in the wireless phonographs; as a local oscillator in every superheterodyne receiver and in the high frequency oscillator of induction heaters. Typical application of various oscillators are illustrated on pages 17, 19, 21 and 35 of the Knight-Kit 12-in-1 Electronic Lab manual. These illustrate the use of oscillators in transmitters, code practice and tone generation. Experiments 4 and 5 on these circuits will demonstrate the fundamentals discussed in this chapter.

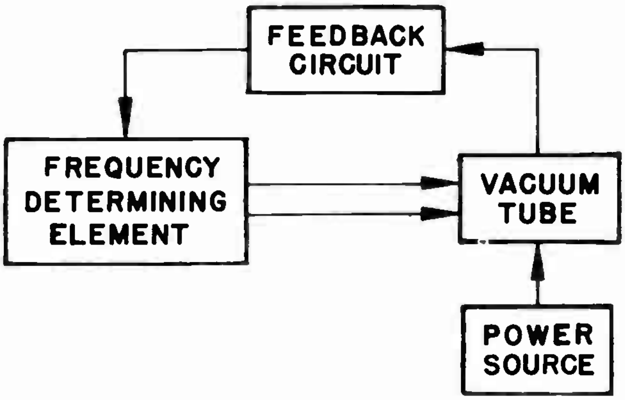


Fig. 24. BLOCK DIAGRAM OF AN OSCILLATOR

Every oscillator consists of at least four components: a vacuum tube; a source of power; a frequency determining element and a feedback circuit. This is shown in Figure 24. The vacuum tube employed is an amplifier. The source of D.C. power, either a battery or a power supply. The frequency determining element can take either of two forms. The most common is the inductance-capacitance resonant circuit or "tank circuit" as it is called. The second type uses components that are equivalent to a resonant circuit such as a quartz crystal. The feedback circuit may be inductive or capacitive. These elements are arranged in a circuit similar to that of a Class C amplifier with the added feature of feedback so that a portion of the A.C. output is fed back as input to the oscillator grid. This feedback must be of proper phase to overcome all input circuit losses and cause sustained oscillations to exist without external excitation. Oscillators may be divided into one of two main categories, self-controlled oscillators and mechanically controlled oscillators. Self-controlled oscillators use resonant circuits. They have the advantage of being able to easily change frequency to any desired value, within the tank circuit's range, by making the capacitance or inductance variable.

In the mechanically controlled oscillator the frequency is usually determined by the mechanical resonance of a piezo-electric crystal. A change in the frequency of oscillation requires changing the crystal used in the circuit. This oscillator, however, has the advantage of being the most stable.

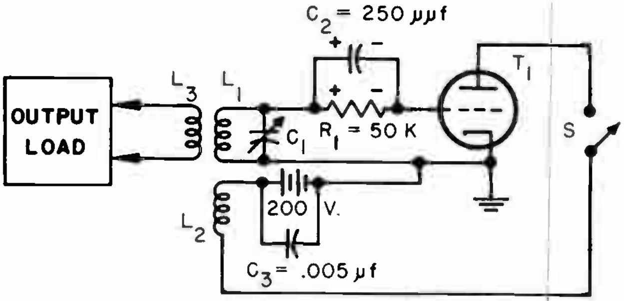


Fig. 25. ARMSTRONG SERIES FED TUNED GRID UNTUNED PLATE OSCILLATOR

Consider the self-controlled oscillator. In this category we find many types, the simplest of which is the Armstrong, Series-Fed, Tuned-Grid, Untuned-Plate oscillator or simply the "Ticker Coil" oscillator. This type of oscillator is used in the Wireless Broadcaster and the Wireless Code Practice Oscillator of the Knight 12-in-1 Kit. In the circuit of Figure 25 a triode, T1, and a 200 volt battery are used. Inductance and capacitance, L1, and C1, determine the frequency and the transformer winding, L2, is the feedback element. R1 and C2, the grid condenser and resistor, provide the bias for T1. L3 magnetically couples the oscillator to its load and C3 bypasses the RF currents around the battery. To see how all of the components work together to form a self-oscillating circuit, insert switch S, which when closed will apply B plus to T1. When S is open no plate current flows and there is no grid bias. At the instant the switch is closed zero bias exists and the plate current immediately begins to increase. This fast-changing-current flows from cathode to plate, through S and L2, bypasses the battery through C3 and returns to the cathode. As this current increases, the magnetic field, which it creates around L2 expands. Since L2 and L1 are windings on the same transformer, this expanding magnetic field cuts the turns of Ll, inducing a voltage, En. This induced voltage immediately sets up a circulating current within the tank circuit, driving the tank into oscillation. During any one cycle of oscillation energy is transferred from the magnetic field around the inductance to the electrostatic field between the plates of the capacitance, then back to the magnetic field around the inductance. For each succeeding cycle this same action repeats itself. This is known as the "fly-wheel effect" of a tank circuit. If we were to suddenly open the switch at this instant, these developed oscillations would not stop immediately. They would continue with each succeeding cycle of circulating current becoming smaller and smaller until eventually all of the energy stored in the tank dissipates itself in the resistance of the tank. To sustain these oscillations it is necessary to supply ample energy to overcome the circuit losses. This is accomplished by a continual feedback. Any energy feedback in .excess of what is necessary to supply grid circuit losses provides an output. Our source of feedback energy was the tank circuit. The current in L2 is a result of the plate current flow thru L2. This current is derived from the battery. The feedback should be in the frequency range of L1 and C1 and must be fed back into the tank circuit properly synchronized or phased so as to aid the already existing oscillations.

There are two ways of supplying B plus to the oscillator tube. One is called Series feed and the other is called Shunt feed. In Series feeding, the source of plate voltage and the RF plate circuit components are connected in series. The D.C. and A.C. components of plate current must both flow through the same path from the plate to cathode of the tube. This method, although the simpler of the two, is not necessarily the more stable.

Shunt feed exists, when the source of plate voltage is connected in parallel with the RF plate circuit components. In this type of feed, the A.C. and D.C. components have separate return paths from the plate to the cathode. Shunt feed allows only the A.C. component of plate current to flow through the feedback element or any part of the tuned circuit. Keeping the D.C. component away from the frequency determining element provides less possibility of changing temperature and causing frequency instability. It also keeps the B plus from the tuned circuit.

A second type of Armstrong oscillator is the Tuned Plate Untuned Grid variety. In this oscillator the operation is exactly the same as for the Tuned Grid, Untuned Plate circuit. The only difference is that the resonant tank, L1, and C1, is placed in the plate circuit and L2 is in the grid circuit.

Many other types of self-controlled oscillators have been developed and are in use in various electronic devices. Their basic operation is similar to that of the Armstrong circuit. For example, the blocking oscillator circuit is employed in both the Code Practice and Light-Controlled Oscillators of the Knight-Kit 12-in-1 Electronic Lab. The relay coil winding provides the proper feedback. Frequency is controlled by varying the charging time of a condenser either by a variable resistance or by a photocell whose resistance varies with the light striking it.

Experiment No. 5

Object:

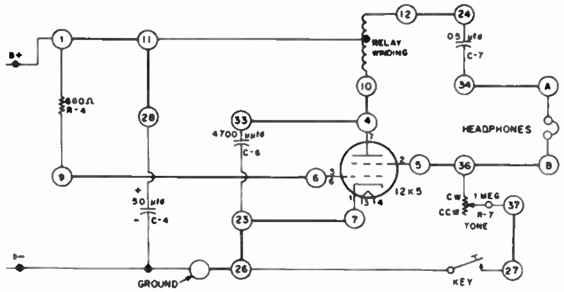
To study the operation of various oscillator circuits.

Apparatus:

1. Assembled Knight-Kit 12-in-1 Electronic Lab.
2. DC Voltmeter.

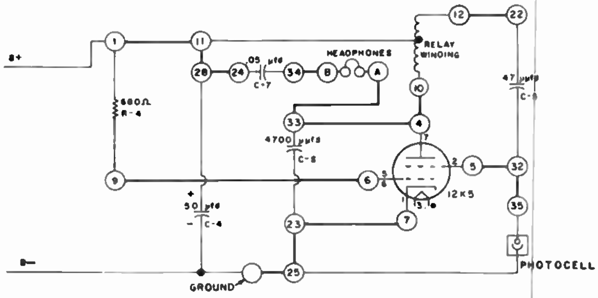
Procedure:

1. Wire the code practice oscillator of the circuit below as per the instructions on page 20 of the 12-in-1 Kit manual. Trace the circuit and compare with the wiring diagram.



Blocking-Type Code Proctice Oscillator

2. Vary potentiometer R-7 and note the effect on the generated tone. Explain.
3. Measure all the 12K5 electrode voltage using the D.C. voltmeter. Measure across terminals 7-1, 2-1 and 5-1.
4. Rewire the 12-in-1 Kit to obtain the light-controlled oscillator as per the instructions on page 34 of the manual. Trace the circuit and compare with the wiring diagram.



Light-Controlled Oscillotor

5. Compare this circuit with that of the code practice oscillator. Note and list the differences. Explain.
6. Vary the light striking the photocell and note the results. Explain.
7. Measure all the electrode voltages again and compare with the readings obtained in part 3.
8. Replace capacitor C-5 with other values of capacitance found in the kit. Note the results and explain.
9. Replace the photocell with a potentiometer from the kit. Vary the resistance setting and note the results. Compare this action with that of the potentiometer.
10. Give an example of an application for this type of oscillator circuit.

VI. THE SUPERHETERODYNE RECEIVER

FIGURE 26 shows the difference between the TRF and superheterodyne receivers. The superheterodyne has a number of advantages over the TRF. In the TRF, a large number of tuned RF stages are required to achieve proper selectivity and sensitivity. As the frequency of tuning is changed, the L to C ratio changes. This changes the Q of the tuned circuit which in turn changes the receiver gain. In the superheterodyne, all incoming signals, regardless of frequency, are changed to one fixed frequency. This new frequency, called the intermediate frequency or I.F., is amplified in an amplifier tuned to that frequency only. This tuning does not have to be varied. The Q of the tuned circuits can be made as high as possible, resulting in a large gain. Except for the I.F. amplifier and the method of obtaining the I.F., the superheterodyne is very similar to the TRF receiver.

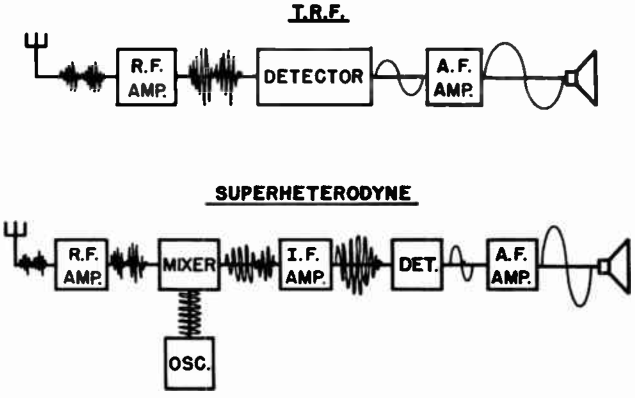


Fig. 26. RECEIVER BLOCK DIAGRAMS

The RF section, mixer, and oscillator tuning capacitors are mounted on a common shaft so that all three may be tuned together. Thus, for an incoming signal of 1,000 kilocycles, the main tuning capacitor is set for 1,000 kilocycles and the local oscillator is tuned to 1,455 kilocycles. As the block diagram indicates, two signals are fed into the mixer; the 1,000 kc RF and the 1,455 kc local oscillator signal. Whenever two signals of different frequency are applied to a vacuum tube circuit, the output will contain a multitude of additional frequencies. The principal frequencies to be found in the output are the original RF, the original oscillator frequency, the RF frequency plus the oscillator frequency and the RF frequency minus the oscillator frequency. In our example, one of the new frequencies in the mixer output will be 1,000 kc plus 1,455 kc or 2,455 kc. The other new frequency in the output will be 1,000 kc minus 1,455 kc or 455 kc. If the original radio frequency signal is selected for the IF, the receiver is merely a straight TRF unit. If the IF stages are tuned to the local oscillator frequency, there will be no intelligence on this signal since the local oscillator supplies RF of constant amplitude. Therefore, we use either the higher frequency signal obtained by adding the RF and the oscillator frequencies, or the lower frequency signal, obtained by subtracting the RF from the oscillator frequency. The lower frequency signal is used in practice. This 455 kc frequency is called the intermediate frequency. It is amplified by the IF stages. These are Class A, RF amplifiers operating at a fixed frequency. Gain for a single IF stage is so great that most of the smaller commercial receivers use only one such stage before detection.

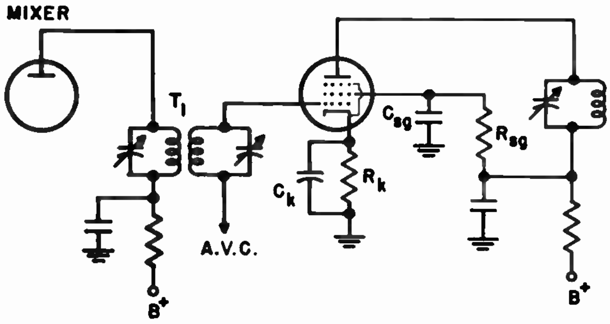


Fig. 27. I. F. AMPLIFIER STAGE

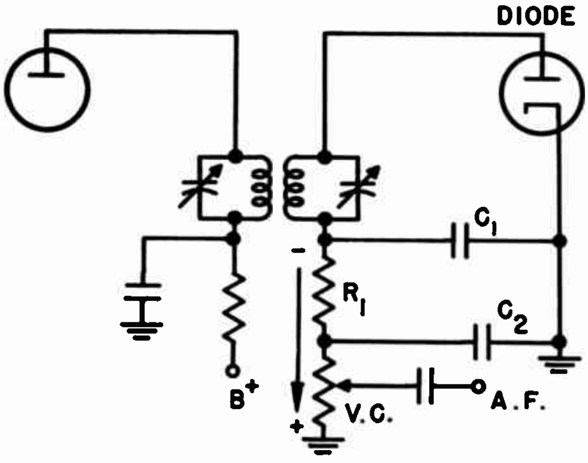


Fig. 28. DIODE DETECTOR STAGE

The most common detector circuit used in superheterodynes is the diode detector. The output of the IF stage is transformer coupled to the detector. This transformer has a tuned primary and secondary. The secondary has one terminal connected to the plate of a diode tube. In the simplest type of detector, the cathode of this tube is connected directly to ground. Figures 27 and 28 show typical IF amplifier and diode detector circuits. The superhet receiver is, thus, a combination of circuits previously discussed and studied experimentally with the aid of the Knight-Kit 12-in-1 Electronic Lab.

VII. ELECTRONIC CONTROL CIRCUITS

Vacuum tubes may be employed as control devices. The amplifier may be applied in conjunction with relays so that input grid signals of proper voltage will cause sufficient plate current to flow to operate the relay. Various types of inputs may be employed in these devices. The human voice can be utilized in this type of circuit. Such a unit is called a voice-operated relay. A typical circuit using this method of operation is described on page 27 of the Knight-Kit 12-in-1 Electronic Lab manual and its circuit is studied in Experiment No. 6. This type of electronic relay is quite commonly used in controlling the plate voltage of transmitter tubes in two-way mobile radio equipment. The transmitter filaments are continuously operated. When a voice signal is directed to an associated microphone, it passes through the relay circuit before being applied to the modulator. The voice signal causes the plate voltage to be applied to transmitter tubes before the audio (voice signal) modulates the RF carrier.

Photocells are frequently employed in relay circuits. A typical photoelectric relay is studied in Experiment No. 6. Its operation is fully discussed on page 23 of the Knight-Kit 12-in-1 Electronic Lab manual.

Various other control circuits are described on pages 25, 29, 31 and 33 of the Knight-Kit manual.

Experiment No. 6

Object:

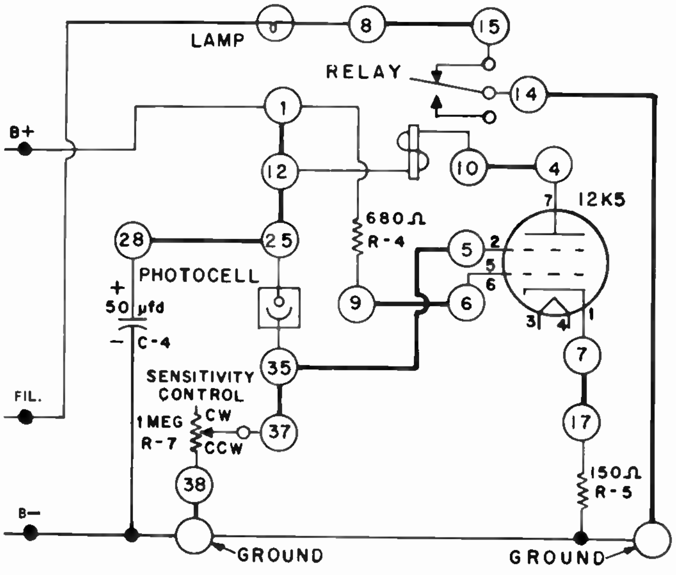
To study the operation of various electronic relay circuits.

Apparatus:

1. Assembled Knight-Kit 12-in-1 Electronic Lab.
2. DC Voltmeter.

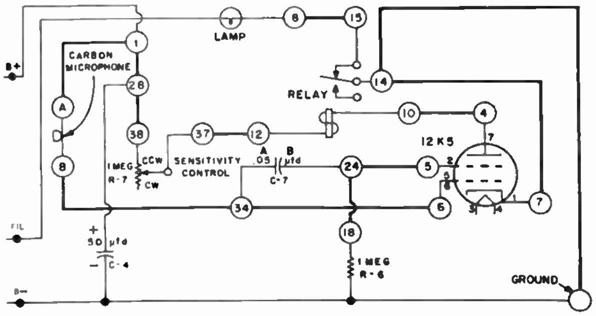
Procedure:

1. Wire the photoelectric relay as per the instructions on page 22 of the 12-in-1 manual. Trace the circuit and compare with the wiring diagram below.
2. Measure all the 12K5 electrode voltages with no light on the photocell.
3. Repeat step 2 with light striking the photocell. Compare the results with those of step 2.
4. Vary R-7 and note the results with both high and low light levels. Explain.
5. Give three examples of applications for this type of circuit.



Photoelectric Relay

6. Wire the Voice-Operated Relay as per the instructions on page 26 of the 12-in-1 manual. Trace the circuit and compare with the wiring diagram.



Voice-Operated Relay

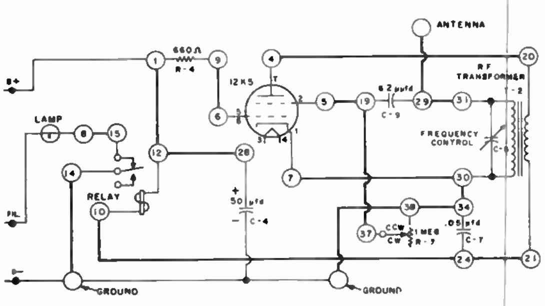
7. Talk into the microphone and observe the results.

8. Vary R-7 and note the effect. Explain.

9. Replace C-7 with other values of capacitance found in the Kit and note the effect. Explain.

10. Replace R-6 with other values of resistance found in the Kit and note the effect on circuit operation. Explain.

11. Wire the capacitance-operated relay as per instructions on page 32 of the manual. Trace the circuit and compare with the wiring diagram.



Capacitance-Operated Relay

12. Measure all the 12K5 electrode voltages.

13. Place the hand close to the antenna and note the effect on circuit operation. Explain.

14. Measure all the electrode voltages while a friend's hand is held near the antenna. Compare with the results obtained in step 12.

15. Give three examples of applications for this circuit.

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