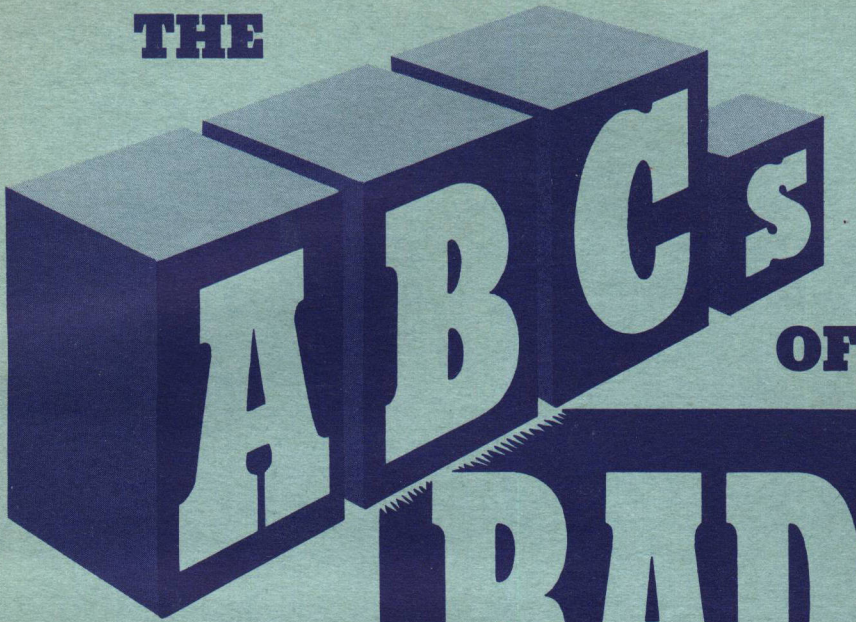


THE



RADIO

★ ★ ★

Written So You
Can Understand It

★ ★ ★

PREPARED BY THE
**RADIO AND TELEVISION
DIVISION**

RADIO RECEIVER DEPARTMENT
PRODUCT SERVICE SECTION
GENERAL ELECTRIC COMPANY



Price 25¢ 35

The **ABC'S** of **RADIO**

**This book is intended to help the beginner
understand the fundamentals of radio.**



GENERAL  **ELECTRIC**

**RADIO AND TELEVISION DIVISION
RADIO RECEIVER DEPARTMENT
PRODUCT SERVICE SECTION**

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P R E F A C E

This book is the outgrowth of a training course in radio that was prepared for sales personnel and others employed in non-technical positions in the radio industry. Its purpose is to give them a background of understanding of radio principles, particularly as applied to radio receivers and the servicing of receivers, in as simple language as possible.

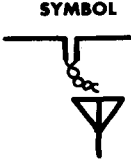
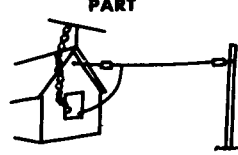

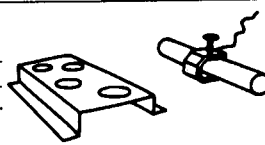
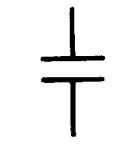
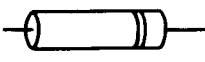
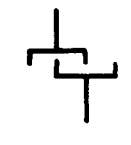
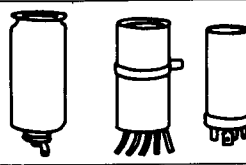




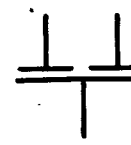

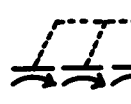
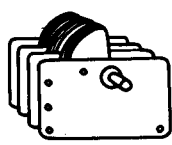
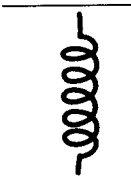
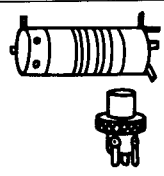
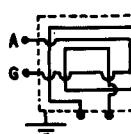
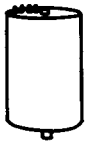
The scope of the material is broad, with mathematical and engineering treatment on fundamental theory purposely held down to a minimum. Hence, the point of view of the practical serviceman has been adopted rather than that of the advanced engineer.

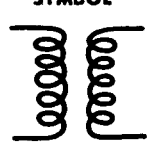
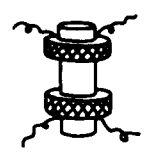
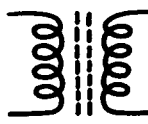
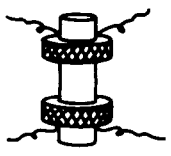
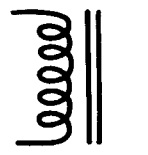
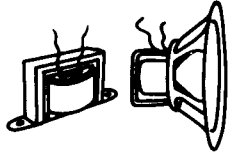
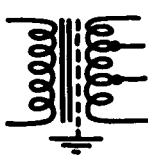
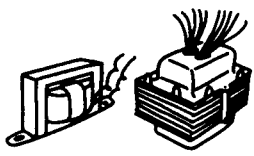
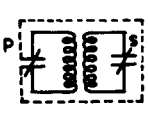
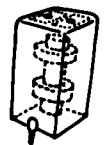
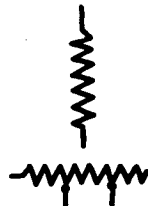
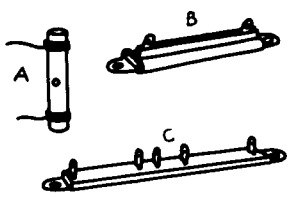
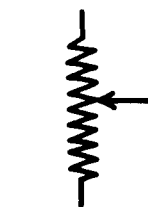
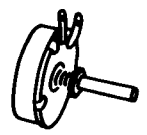


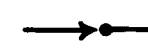
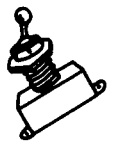
It is realized that for a thorough knowledge of the principles of modern radio, further study is needed. Students are, therefore, referred to the many outstanding textbooks dealing with all phases of the radio art.

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SYMBOLS AND ABBREVIATIONS

SYMBOL	PART
	Antenna and dipole antenna. Abbreviation A. or ANT. 
	Ground or chassis connection. Abbreviation G. or GND. 
	Fixed condenser. Abbreviation C. 
	Electrolytic condenser. Abbreviation C. 
	Variable gang condenser. Abbreviation C. 
	Variable trimmer or padding condenser. Abbreviation C. 
	Two condensers in one container with common lead connection. Abbreviation C. C. 
	Gang condenser with three sections. Dotted lines indicate common shaft. 
	Fixed coil or inductor, air core. Abbreviation L. 
	Loop antenna with primary winding for external antenna and ground connections. Dotted lines indicate electrostatic shield. Abbreviation L. or T. 

SYMBOL	PART
	Transformer, air core. Abbreviation T. 
	Transformer, powdered iron core. Abbreviation T. 
	Coil or inductor with iron core. Abbreviation L. 
	Transformer, iron core. Dotted line indicates electrostatic shield. Abbreviation T. 
	Transformer, air core, with primary and secondary windings tuned by trimmer condensers. Dotted line indicates shield can. Abbreviation T. 
	Fixed resistors. A. Carbon. B. Wirewound. C. Tapped wire wound. 
	Variable resistor. 
	Light bulb. 
	Switch—single pole, single throw. 

SYMBOLS AND ABBREVIATIONS

SYMBOL	PART
	Switch—multi-contact.
A B C D E	A Wires connected. B, C. Wires crossing but not connected. D. Two wires twisted. E. Wire surrounded by grounded shield.
	Wires connected by means of plugs.
	Phonograph motor and turntable.
A B	Phonograph pickups. A. Crystal pickup. B. Magnetic pickup.
	Power plug and outlet.

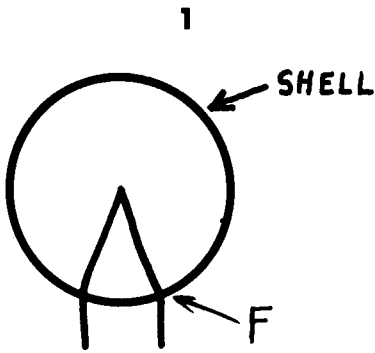
SYMBOL	PART
	Single-cell battery.
	Multicell battery, series connected.
	Multicell battery, parallel connected.
	Dry disc rectifier.
	Vibrator (S. Solenoid coil. C. Contacts. R. Vibrating reed).
	Dynamic speaker, permanent magnet field type.
	Dynamic speaker, electromagnetic field type.

Common Abbreviations and Expressions

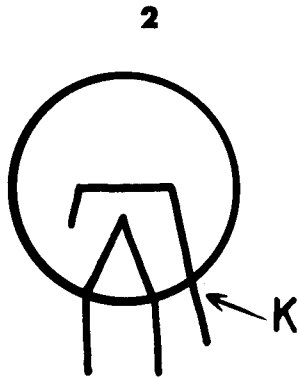
Alternating current.....a-c
 Amperea
 AntennaAnt.
 Audio frequency.....a-f
 Bias voltage.....C-voltage
 Continuous waves.....CW
 CrystalXtal
 Cycles per second..... \sim and c.p.s.
 Decibeldb
 Direct current.....d-c
 Electromotive force.....e.m.f
 Filament voltageA-voltage
 Frequencyf
 GroundGnd.
 Henryh
 High voltage.....B-voltage

Intermediate frequency.....i-f
 Kilocycles per second.....kc
 Kilowattkw
 Megacycles per second.....mc
 MegohmM Ω
 Microfarad μ f
 Microhenry μ h
 Micromicrofarad $\mu\mu$ f
 Microvolt μ v
 Microvolt per meter..... μ v/m
 Milliwattmw
 Ohm Ω
 Radio frequency.....r-f
 Switch.....S- or SW.
 TransformerT. or Xformer
 Voltv

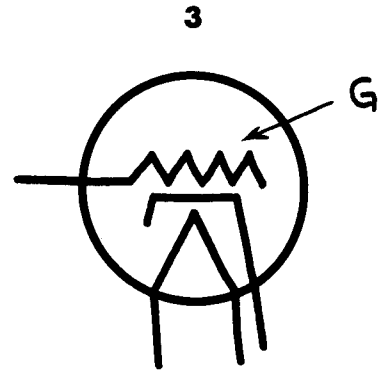
TUBE SYMBOLS



Filament (F.) or heater (H.) and envelope.



Cathode (K.) added.



Grid (G.) added.

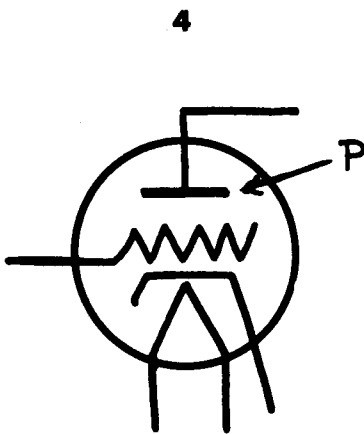
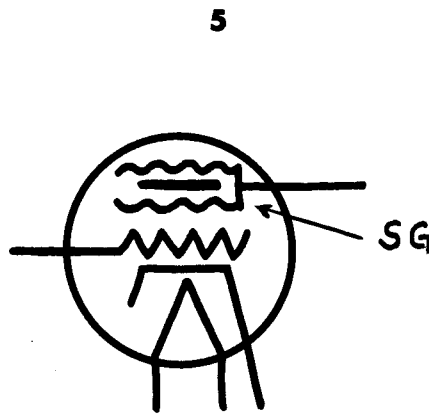
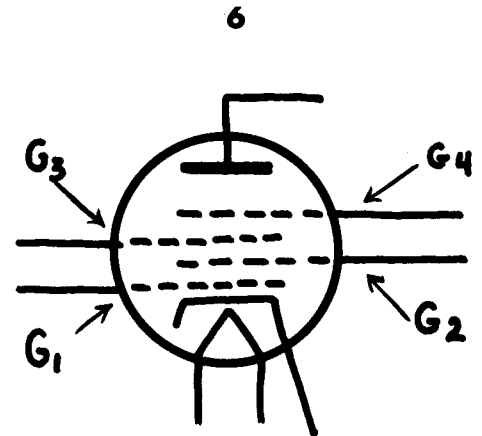


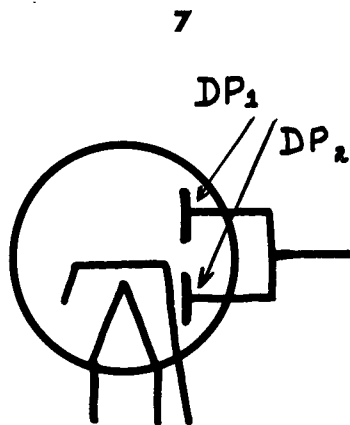
Plate (P.) added.



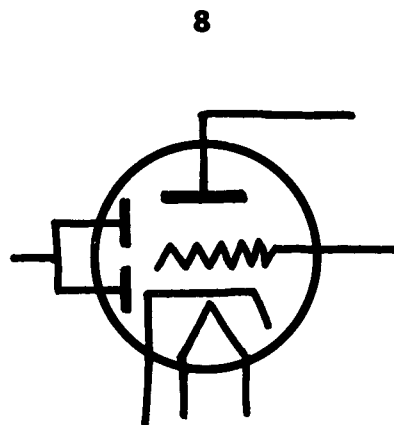
Screen grid (SG) added.



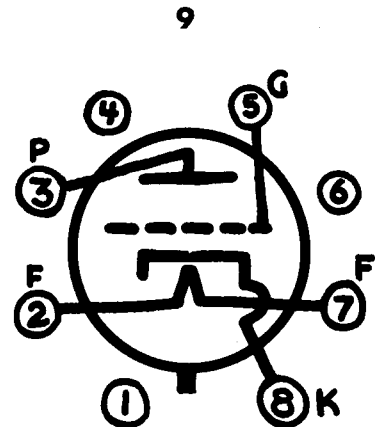
*Multigrid tube. Grids are numbered successively from cathode towards plate.



Heater type diode—two diode plates (D.P.) common cathode (K.).



Triode elements added to 7 forms duodiode triode.



Base connections, under view, indicating element connections to base. Pins are numbered clockwise, starting at locating key on octal tubes.

*Grids are drawn either as broken lines or zigzag

WAVE AND ELECTRON THEORY

Many analogies have been used to illustrate how radio, light and sound waves behave. We are familiar with such examples as waves traveling on water or a flag blowing in the breeze. They are waves of slow speed and hence are visible to the eye. Some external force starts the waves and if needed the waves could be used to perform some service since they are carrying energy.

It should be remembered that all waves carry energy or power. In these visible waves it is evident that the materials carrying the waves do not in themselves move along at the speed of the waves. The material is merely the medium through which the waves of energy are transmitted.

It is apparent that the distance from one crest of these waves to the next, representing the length of the wave (wavelength), will be greater when fewer waves pass in a given length of time than when a great number pass in the same length of time and at the same speed. This proves the relation of wavelength to frequency. The fewer the waves that pass in a given length of time, the farther apart they will be and the lower the frequency of their passing.

In radio, we are chiefly interested in radio waves and sound waves. Radio waves are transmitted through a medium called the ether and at the speed of light waves, 186,000 miles per second. Sound waves are transmitted through air at a speed of only about 1100 feet per second.

Radio waves travel as electromagnetic and electrostatic fields with the energy evenly divided between the two. The electrostatic lines of force and the electromagnetic lines of force are at right angles to each other in a plane perpendicular to the direction of propagation.

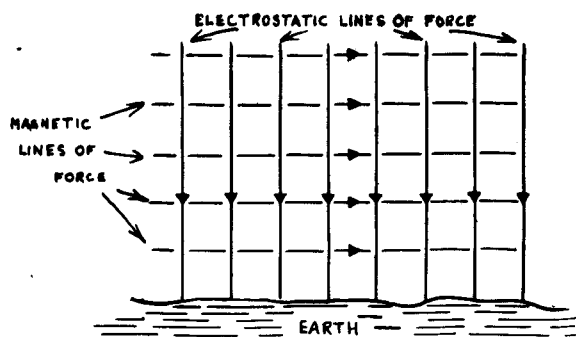


Fig. 1. Arrows indicate instantaneous directions of the fields for a wave traveling out of the page toward the reader.

The wave is considered polarized in the direction of the electrostatic lines of force. When the direction of the electrostatic lines is parallel to the earth's surface, the wave is considered horizontally polarized and when they are at right angles to the earth's surface it is considered vertically polarized, dictated by the transmitting antenna.

Except at ultra high frequencies, two waves are propagated, one travels above the ground called the sky wave and one travels on the surface of the ground called the ground wave. The energy of the

ground wave does not carry for long distances, whereas almost all distant radio reception is attributed to the sky wave. Sometimes there is more than one sky wave and when two or more sky waves arrive at a radio receiver at different times, they conflict with each other causing a distorted signal known as "selective fading." This condition also occurs if the ground wave and sky wave get out of step.

When a radio receiver picks up a radio wave carrying some kind of intelligence (speech, music, code, etc.), the wave induces a signal into the receiver at a value of possibly one millionth of a watt. The primary job of the receiver is to build up or amplify this weak infinitesimal signal to a value in the neighborhood of one watt or more, so that enough power is available to drive the loudspeaker, which changes the intelligence into sound waves. In this case, we must amplify one million times.

The device used to do this amplifying job is the electronic tube. The tube obviously does not create this power. It takes the signal power and mixes it with a local electrical power, passes it onto the next tube in the circuit, until step by step it has been built up to the desired power level, to drive a loudspeaker.

This signal amplifying job is only one function of the receiver.

Other functions that must be performed are:

- The selection of the desired signal from among many others vibrating in the ether.
- The reproduction of the sound from the loudspeaker as closely as possible to that existing at the source.
- The elimination or reduction of undesirable "extras" such as noise and static.

Sound waves are produced by the vibration of some material in a medium which is compressible and which also can expand. Air is such a medium (also metals, glass, water, etc.). The medium must also be elastic, that is, it must tend to resume its natural state if compressed or expanded. Those materials which do not tend to resume their previous or natural state after having been compressed or expanded are poor conductors of sound energy and are used as shields from sound.

The lower frequency vibrations of a radio loud speaker can usually be seen, and if the air in front of the speaker were visible, one could see the sound wave as a series of dense areas and rarified areas.

Considering one vibration cycle of the speaker diaphragm, when the motion starts in a direction we'll consider as "out," the air is pushed and becomes a dense area of air molecules and travels away from the speaker. When the diaphragm reverses its direction, it is pulling at the air in front, which becomes rarified. Now there is an area of few air molecules.

This wave of dense and rarified areas travels away from the speaker at the speed mentioned previously. When this "wave train" strikes any free-to-move object, that object will be moved back and forth.

Radio theory is one of the more complex branches

of the study of electricity which deals especially with the generation, transmission, and reception of high frequency electrical power as a means of conveying intelligence. In our study we will be interested only in radio principles as they apply to receivers. Much of our work, however, involves the use of basic electrical principles, so a review will be made.

THE ELECTRON THEORY

Electricity itself is a mystery, however it is a form of energy that we have learned to control easily and to make it serve our needs in many ways. No one actually knows its real nature.

We know that an electric current is invisible — we can't see or hear it. However, we can see and hear the things which an electric current can do. We know that, if we press a door bell button, the bell will ring, or if we throw a switch a lamp will light and stay lit until we open the switch circuit. Under the right circumstances electricity will produce heat, light, magnetism, chemical action and certain rays.

Scientists have propounded a theory to explain electricity, called the electron theory. This states that all substances are made up of tiny particles of negative electricity called electrons, which can travel at many thousands of miles per second. An electric current is a moving procession of electrons. Their size is so small that millions of electrons are required to heat the filament of a flashlight bulb.

The smallest subdivision of any substance which still retains the properties of that substance is considered the molecule. All matter is made up of such fundamental units. The molecule in turn is divided up into smaller units called atoms, which make up the basic elements of the substance.

Composing each atom are still smaller particles of electrical charges. The number and pattern of these charges determine the difference between one atom and any other. The nucleus of an atom is made up of negative and positive charges, the positive charge predominating. Whirling around this nucleus are still more electrical charges called electrons. These electrical charges on an atom are usually electrically balanced, with some of the electrons tightly bound to the nucleus while others readily respond to an outside influence and can be broken away. When an electron is broken away from an atom, the atom's balance is disturbed and what happens as a result of this unbalance is the basis for electrical theory.

The effect of electrons at rest is called the static effect and is the form of electricity most widely found in nature. More important to our daily chores and to radio receivers is the effect produced when large numbers of electrons are in motion.

In many substances, such as glass for instance, the electrons are attached securely to the atoms of the material and can only be broken loose with great difficulty. These substances are insulators. In metals, however, there are large numbers of free electrons or electrons which are not attached and can move more or less freely through the metals. Metals are therefore good conductors of electricity.

As an example, in Fig. 2a is shown a cross section

of a piece of copper wire through which no current is flowing. Here the electrons are moving from atom to atom in such a helter-skelter fashion as to make negligible the average motion in any one direction. However, if the ends of the copper wire are connected to the terminals of a battery as shown in Fig. 2b, the electrons are caused to drift from atom to atom toward the end of the wire connected to the positive battery terminal.

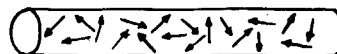


Fig. 2a. Electrons with no current flowing.

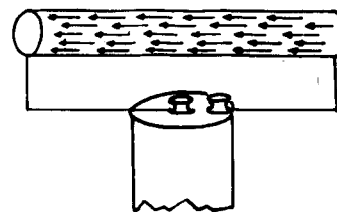


Fig. 2b. Electron current flowing.

This orderly parade of electrons is an electric current.

Water is considered as a non-compressible fluid. There are really large spaces between the water molecules, but it is difficult to actually crowd them together or to compress water. We may similarly treat electrons in a metal as an uncompressible fluid. There are large spaces between them and yet on account of their great repulsion for one another, they are hard to compress.

Always bear in mind that electrons are considered to be **NEGATIVE** electricity. It will make it easier to analyze and understand electrical theories. As an example, when a potential difference exists in an electrical circuit, the **ELECTRON** current flow is from the negative or minus side of the voltage source, through the external circuit, to the positive side of the source.

REVIEW QUESTIONS

1. What is the speed of
 - a. Radio waves?
 - b. Sound waves?
2. What determines the polarization of a radio wave?
3. What general paths do radio waves traverse? What is the effect of received radio waves arriving over different paths "out of step"?
4. What is the average order of amplification required of a radio receiver?
5. Is rubber a good conductor of sound waves? Why?
6. What polarity is an electron considered to be?
7. In what direction is electron current flow in an electrical circuit?
8. Why is wood a rather poor conductor of electricity?
9. What must occur to an atom to have a manifestation of electrical action?

DIRECT-CURRENT THEORY

In radio circuits we find electric current in two different forms — direct and alternating.

An alternating current changes its direction of flow at regular intervals, but direct current flows constantly in the same direction.

VOLT—THE UNIT OF ELECTRIC PRESSURE

Electricity exerts a sort of pressure which is not called "pressure" in electrical language but is referred to as potential or voltage. Just as water pressure is needed to cause a flow of water, so a voltage is required to cause a flow of electrons through a wire. The practical unit of electric pressure is the volt.

AMPERE—THE UNIT OF CURRENT

An ampere of electric current means that 6.3×10^{18} electrons pass a given point each second. Thus an ampere is a measure of the rate of flow of electrons just as "gallons per second" is a measure of the rate of flow of water. A current of two amperes represents twice as much electricity as a current of one ampere.

OHM—THE UNIT OF RESISTANCE

An ohm is the measure or unit of electrical resistance. Just as small pipes conduct less water for a given water pressure, so small wires conduct less current for a given electric pressure.

The ohm is the practical unit of resistance and is defined as that resistance which will allow one ampere to flow if one volt is impressed across its terminals.

A simple analogy to better understand these three terms is to consider a water pipe fed by a pump.

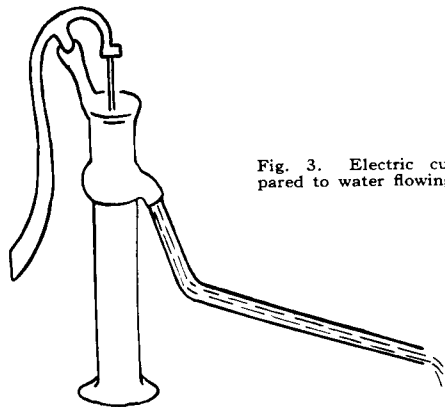


Fig. 3. Electric current compared to water flowing in a pipe.

The pressure exerted on the stream of water is analogous to the voltage in an electrical circuit.

The quantity of water flowing through the pipe per unit of time compares to the current. The friction between the water and the pipe compares to the resistance.

Current flowing in an electrical circuit or wire encounters an electrical "friction" termed resistance. This friction, like mechanical friction, represents energy lost and is likewise dissipated in heat. Any wire circuit will have resistance, but when too much resistance is not desired, wires are used which are

of low resistance material and large enough to carry the current of the circuit.

In other circuits, resistance is desired to perform a certain function. In this case special material of high or great resistance is used, such as carbon, special iron alloy wire, etc. A small piece of such material can have as much resistance as a copper wire hundreds of miles long. A unit made up like this is called a resistor.

OHM'S LAW

Ohm early in the 19th century discovered that the ratio of the pressure to the current in a given circuit is constant. This is the fundamental law of the flow of electric currents. This may be written as:

$$R = \frac{E}{I} \quad \text{where } R = \text{resistance in ohms}$$

$$E = \text{pressure in volts}$$

$$I = \text{current in amperes}$$

$$E = I \times R \quad I = \frac{E}{R}$$

Thus if 2 volts is applied to a 2-ohm resistor, 1 ampere of current flows. Likewise 1 ampere flows through 2 ohms of resistance when there is a 2-volt difference in potential on the resistor, or if 1 ampere flows in a circuit having 2 volts pressure the resistance must be 2 ohms.

Ohm's Law may be applied to an entire electric circuit or to any part of the circuit. When it is applied to an entire circuit, all values of E, I and R must be considered. Similarly for any part of a circuit only the associated values are used.

RESISTORS IN SERIES

If several resistors are connected in series, it is merely necessary to add up their total resistance in ohms and consider the sum as exactly one resistance of that amount.

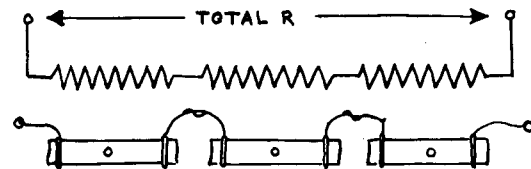


Fig. 4. Resistors in series.

RESISTORS IN PARALLEL

When the resistance in a circuit is made up of two or more resistors in parallel, it is an entirely

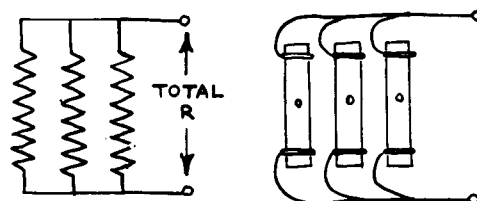


Fig. 5. Resistors in parallel.

different situation. The effective resistance is less than that of the smallest resistor in the group.

The effective resistance is found by the reciprocal equation

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

The reciprocal equation for only two resistors in parallel can be simplified to the following:

$$R = \frac{R_1 \times R_2}{R_1 + R_2}$$

The power used up in heating a resistance can be determined by the following relations:

Where W = power in watts.

$$W = I \times E$$

$$W = I^2 \times R$$

$$W = E^2 \div R$$

REVIEW QUESTIONS

1. What are the terms and abbreviations to denote
 - a. Electrical pressure?
 - b. Resistance?
 - c. Current?
2. State Ohm's Law in your own words.
3. A 100-ohm resistor and 50-ohm resistor are connected in series. What is the total resistance?
4. A 200-ohm and 100-ohm resistor are connected in parallel. What is the total resistance?
5. What is the effect of resistance in an electrical circuit?

INDUCTANCE THEORY

MAGNETIC FIELD SURROUNDING A CONDUCTOR

When a current flows through a conductor, magnetic lines of force surround the conductor. This can be demonstrated by placing a compass needle close to a wire carrying a direct current. The fact that the needle always turns to a right angle to the length of the wire shows that it is being acted on by a magnetic force. The direction of these lines of force depends upon the direction of the current. The greater the current, the greater is the magnetic field. Likewise, the magnetic lines of force are distributed uniformly along the entire length of the conductor. The direction of the lines of force around a wire may be determined by using the following "Right Hand Rule": Grasp the wire with the right hand with thumb extended in the direction in which the current is flowing; then the fingers will be pointing in the direction in which the magnetic lines of force encircle the wire.

By winding a wire conductor into a coil the magnetic field strength inside the coil is concentrated and the flux density is increased. When a direct current is passed through this coil, it has properties similar to a permanent bar magnet.

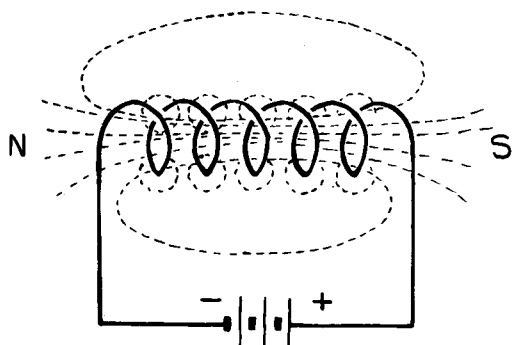


Fig. 6. Magnetic lines of force surrounding a coil of wire.

Fig. 6 shows the lines of force surrounding a few turns of a coil. Since the circular lines of force surround each turn for its entire length and the lines of force are all pointed in the same direction, the resultant will be a combination into a strong field.

INDUCTANCE OR SELF-INDUCTION

Since the magnetic field is proportional to the current, if the current flowing in a coil is varied in any way, the magnetic field also varies. This varying field sets up in the wire itself a counter or self-induced voltage which always opposes the change which produces it.

Because the self-induced voltage opposes any change whatever in the current flow, it is evident that the result would be to lengthen the time required for the current to build up to its final value when a voltage is applied across the coil. (Fig. 7).

Energy is stored in the surrounding magnetic field simultaneously with the current build-up in the coil. When the current is interrupted, the mag-

netic flux collapses and returns the stored energy to the conductor by producing electrical energy. This electrical energy may in turn produce a very high voltage causing a spark or arc when the circuit is opened.

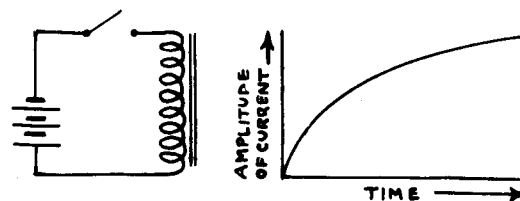


Fig. 7. Current flow through inductance.

UNIT OF INDUCTANCE

The inductance of a coil is simply a measure of the magnetic flux produced per ampere of current. The unit of inductance is the henry. One henry of inductance has one volt back e-m-f or internally generated voltage when the current through the inductance coil changes at the rate of one ampere per second. The symbol for inductance is L .

Iron core coils are used where large values of inductance are required, such as in power supply filter chokes, transformers, etc. Iron being a magnetic substance greatly increases the flux produced by a given current. A suitable silicon steel core may increase the inductance of an air core coil by several thousand times. Thus for a given inductance a much smaller coil with fewer turns may be used.

Powdered iron cores or plugs have some use in small r-f coils such as used in i-f transformers having inductances of 1 millihenry (.001 henry). The gain in inductance is about 2/1. At radio frequencies, the iron core must consist of extremely small particles insulated from each other in order to reduce losses which otherwise would more than offset the value of the small increase in inductance and the slight reduction in losses normally obtainable.

Coils wound on insulated forms and having air cores are generally used for all r-f and i-f circuits. The values of inductance commonly used run from 1 microhenry (.000001 henry) or less for high frequencies to about 200 microhenries for the broadcast frequencies. I-f transformer coils have values in order of 0.5 to 2.5 milihenries.

AMPERE TURNS

A coil of wire carrying a current can be used in a radio to supply a strong magnetic field such as for an electro-dynamic speaker. Since the total magnetic flux depends upon the number of turns and the current strength, it can be expressed in ampere turns.

When only small values of current are available, a large number of turns is necessary to establish an appreciable amount of magnetism, whereas when a large current is available, only a relatively few turns of wire are required.

INDUCTANCES IN SERIES

Inductances connected in series as shown in Fig. 8 simply add their self-inductances together, since

each one helps to oppose any change in current through the entire system. Thus three coils having inductance as of 75, 125 and 10 microhenries would

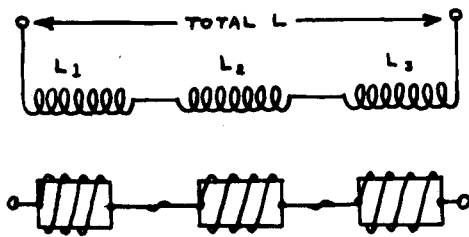


Fig. 8. Inductances in series.

have a combined inductance when connected in series of $75 + 125 + 10 = 210$ microhenries.

It is common practice to connect inductances in series to increase the total inductance. Such inductances are called "loading coils."

INDUCTANCES IN PARALLEL

Where inductances are connected in parallel, their combined inductance is expressed:

$$\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}$$

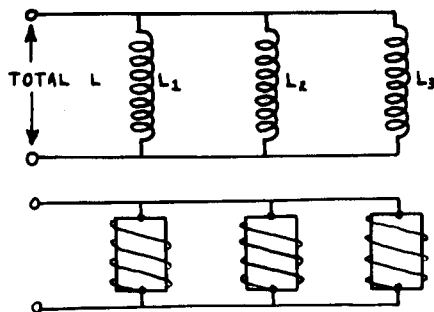


Fig. 9. Inductances in parallel.

Where L is the total inductance of the coils whose separate inductances are L_1, L_2, L_3 , no magnetic coupling should exist between the coils when using this formula. From the above, it is evident that the inductance of the coils in parallel is always less than the inductance of the smallest coil alone. This is the same as for resistors connected in parallel.

Care should be taken when using these formulae to make sure all inductances are expressed in the same units, such as henries, microhenries, or milli henries.

REVIEW QUESTIONS

1. What is the abbreviation for inductance? Term for unit?
2. What is the effect of coiling wire carrying current?
3. What does an inductance oppose?
4. What surrounds a wire or coil of wire carrying electrical current?
5. What core material is usually used in inductances used for
 - a. Radio frequencies?
 - b. Power transformers?
 - c. Why?
6. When an inductance is connected to an electrical circuit, does the current flow through the inductance reach maximum value instantly?
7. Is the total inductance greater or less when two or more inductances are connected
 - a. In parallel?
 - b. Series?
8. What characteristic has an inductance compared to a magnet?

MAGNETIC INDUCTION THEORY

VOLTAGE PRODUCED BY MAGNETIC FIELD AND COIL

We found that, if we pass a current of electricity through a coil, the coil would maintain a strong magnetic field which would have the same characteristics as a magnet. Conversely, a voltage can be set up on the coil of wire if a magnet is moved near it. In Fig. 10 if a magnet is rapidly moved into a coil of wire in the direction shown in (a), a current will flow in the circuit in the direction shown. Now if the direction of motion of the magnet is changed and withdrawn from the field, a current in the opposite direction will flow. By moving the magnet back and forth in the coil rapidly, an alternating current will flow and will be proportional to the strength of the magnetic field, the number of turns in the coil and the speed at which the magnet is moved back and forth.

When a conductor is moved through a magnetic field, electrons are moved and electrical current results. Also, an electrical current is generated by a magnetic field moving past a conductor.

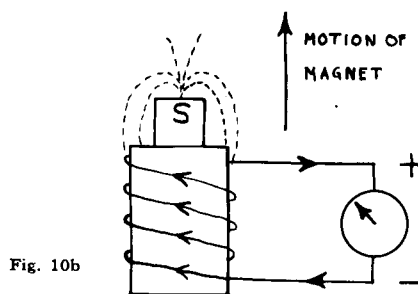
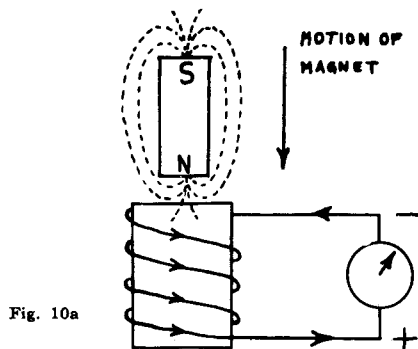


Fig. 10. Production of electric current from a moving magnetic field.

MUTUAL INDUCTION-TRANSFORMER

From the above, it can be seen that if we send a changing current through a coil and bring it near a second coil so that the changing magnetic field of the first coil interlinks the second, we will be able to produce a voltage in the second coil. This is the principle of the transformer. The winding into which the current is sent is always the primary. The winding in which the voltage is induced by electromagnetic induction or which delivers the energy is called the secondary coil.

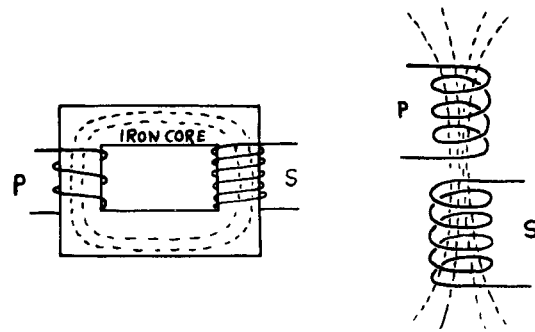


Fig. 11. Power is transferred from one coil to the other by the magnetic field.

The lines of magnetic force of the primary coil which do not interlink the secondary coil are called leakage lines of force or leakage flux. Since they do not contribute in producing induced voltage in the secondary coil, it is important to keep the leakage flux as low as possible. This is accomplished in power and audio transformers by winding the two coils on a core of some highly permeable magnetic material such as soft iron. Two advantages result from this construction. First, the leakage flux is greatly reduced, since practically all the magnetic field will be within the core and will therefore thread through the secondary coil. Also, since the iron core is a good magnetic material, a much greater magnetic field is now available for the same primary turns and current. Leakage flux also induces an opposing voltage in the primary which has the same effect as though a resistance were placed in series with the primary winding so as to reduce the available primary current and so reduce the induced voltage in the secondary. This is called leakage reactance.

Transformers having air cores are used in radio circuits where the frequency is so high that heavy losses due to hysteresis and eddy currents would occur in iron cores. Where the frequency of the primary current is comparatively low as in the case of audio and power transformers, soft steel cores are used because of their higher efficiency in transferring energy from primary to secondary.

By constructing the core of thin laminations of steel, each one electrically insulated from the other as shown in Fig. 13b, the eddy currents are weak because they are confined to a single lamination and the resistance path is very much greater than in a large single chunk of iron. The iron is, therefore, continuous in the magnetic path but is broken for the eddy current path, thereby raising the transformer efficiency.

Another form of transformer loss is called hysteresis loss. When a piece of iron is subjected to a varying magnetic field, the magnetism produced in it lags behind the magnetizing force. Since the atoms of iron do not easily change their position as is required when iron is magnetized, a certain magnetic force is required to change them around. Some of the applied electric current is used up in changing the magnetism of the iron. Soft iron and annealed silicon steel offer less opposition to changing magnetism than the harder forms of iron and tempered steel.

More power cannot be taken from the secondary of a transformer than is taken from the line by the primary. If this were possible, it would violate all laws of conservation of energy. Transforming a given voltage to a higher or lower value will cause an inverse transformation in the current. The product of current and voltage would be the same with high voltage and low current as the product of low voltage and high current, the difference being in the impedance of the circuit.

The transformer, therefore, can be seen as a desirable device to connect circuits of different impedance values. This process is called impedance matching.

TRANSFORMER RATIO

A transformer is used for three purposes in radio receivers: (1) voltage transformation, (2) current transformation, and (3) impedance matching. In all cases, the turns ratio is the factor deciding whether the resulting voltage, current or impedance is raised or lowered.

The induced voltage is proportional to the ratio of the number of primary turns to secondary turns. By using the proper turns ratio, voltages either greater or less than the primary voltage may be obtained at the secondary terminals.

The ratio of secondary impedance to primary impedance of a transformer is equal to the square of the turns ratio. This relation is used many times in radio circuits.

THE AUTO-TRANSFORMER

An auto-transformer is a transformer in which the secondary winding is connected to the primary winding. This type of transformer may either step up voltage as shown in Fig. 12a, in which case the primary winding is part of the secondary; or it can step down voltage as shown in Fig. 12b, in which case the secondary winding is part of the primary.

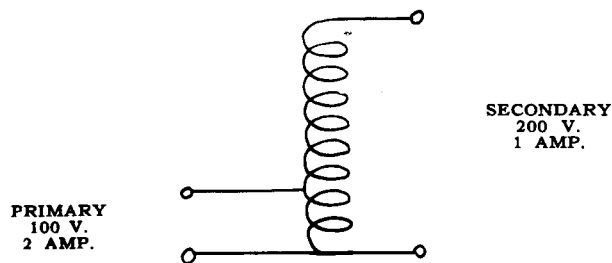


Fig. 12a STEP-UP

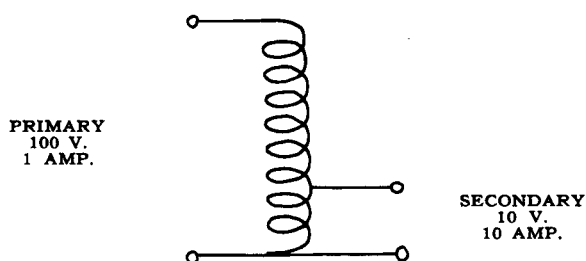


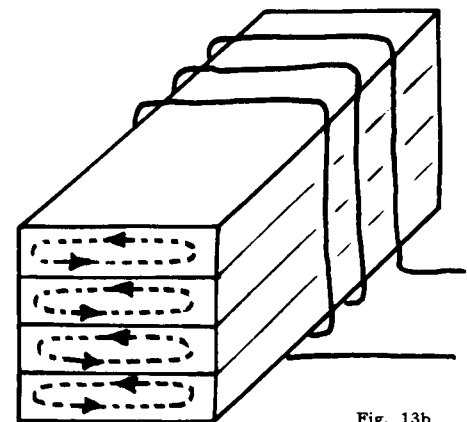
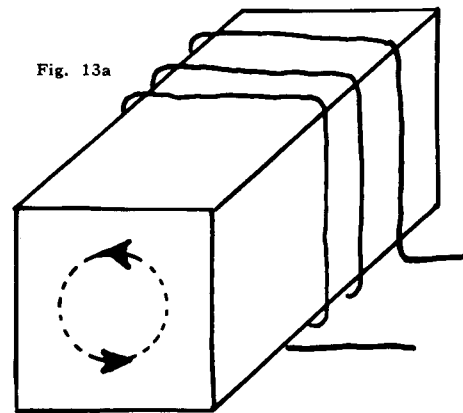
Fig. 12b STEP-DOWN

The voltage, current and impedance relations are identical as these studied for the regular transformer and are determined by the turns ratio.

Air core auto-transformers are often used in input or antenna circuits of receivers.

TRANSFORMER LOSSES

If a solid steel core were used for transformers the core might be considered as a single turn secondary which would have a low voltage induced in it by the rapidly varying magnetic field through it. This would produce circular currents of large magnitude and would produce the same effect as a shorted turn inside of the core as shown in Fig. 13a. This current flowing around the core causes a considerable amount of heat, which would quickly heat the core and winding and decrease the efficiency, since this current is wasted. These currents are called "eddy currents."



REVIEW QUESTIONS

1. What principle makes a transformer possible?
2. Are transformers perfect machines?
 - a. Why?
3. What type core construction is usually found in power transformers and why?
4. How is a transformer used to connect circuits of different impedance values?
5. What determines the current, voltage and impedance ratio of primary and secondary of a transformer?

CAPACITANCE THEORY

CONDENSER OR CAPACITOR

In radio circuits, capacitors play just as important a part as coils or inductances. Wherever an inductance is used in the circuit, a capacitor is usually used with it. A condenser or capacitor may be defined as "any two conductors between which a difference in voltage exists, and which are separated by an insulator or dielectric." Continuous or direct current cannot flow through a condenser because of the insulation between the plates. A steady d-c potential applied to the capacitor plates, however, will cause them to become charged; that is, the capacitor stores electrical energy.

The action of a capacitor is explained by the electron structure of matter and is caused by the displacement of electrons in the conductor and dielectric. Let us consider the capacitor shown in Fig. 14, consisting of two metal plates (a, b), separated by the dielectric (c), such as air or mica.

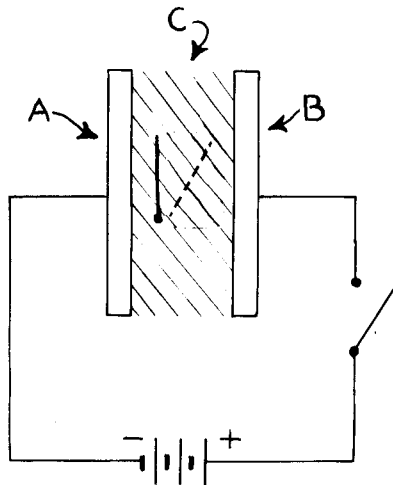


Fig. 14. Electron action in a condenser.

Since electrons are attracted by a positive charge but repelled by a negative, if we make plate (a) negative, the electrons in (c) will be repelled by (a) but attracted by (b). We saw previously that an insulator will not conduct an electric current because an insulating material does not have free electrons. However, the electrons in an insulator can be displaced or stretched out of place in relation to the fixed atoms, if a high enough voltage is applied. In Fig. 14 we have shown a single electron held in place in the insulating material as by a rubber band. When the voltage is applied it stretches out of place as shown in the dotted line. While it is thus moving we have a small instantaneous flow of electric current through the dielectric, then after a short time there will be zero current as long as the applied voltage is kept constant.

If the voltage is removed and a resistor or short placed across the capacitor terminals, the electrons, by reason of the elasticity in their bonds, will return to their neutral position, causing a flow of current in the opposite direction to the charging current. Thus we get a current on applying the voltage and a current in the opposite direction when the voltage is removed. The effects produced in these two cases are exactly equal and opposite.

UNIT OF CAPACITY

The unit of capacity is the farad, which is simply the measure of the quantity of electricity stored in a condenser when one volt of external voltage is applied.

This is an extremely large unit, hence in radio the micro-farad (μf), which is one millionth of a farad, and the micro-micro-farad ($\mu\mu\text{f}$), which is one millionth of a micro-farad, is used.

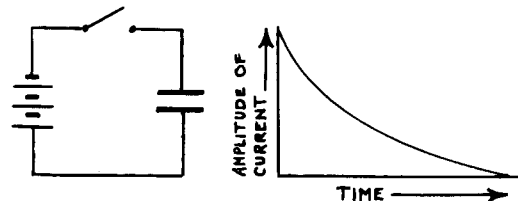


Fig. 15. Current flow through a condenser.

CAPACITY OR CAPACITANCE

The capacity of a condenser for storing electrical energy is called its capacity or capacitance. If the insulation of the condenser were perfect, the condenser could hold its charge indefinitely. This capacity of the condenser depends on three factors: (1) the total surface area of the conductor in actual contact with the dielectric, (2) the thickness of the dielectric, (3) the nature of the dielectric.

TYPES OF CONDENSERS

There are four common types of condensers used in a radio receiver as follows:

Variable condensers use a dielectric of air and are constructed of metal plates formed in a rotor and stator assembly. They come in sizes of 1 to 1000 $\mu\mu\text{f}$ and are characterized by extreme low-loss and stability.

Paper bypass condensers consist of two or more long strips of metal foil separated by thin waxed paper, the complete unit rolled into compact form. Paper condensers are a fixed capacity and have a capacity range from .0001 to 2 μf and are used for audio and r-f bypassing and coupling.

Mica bypass condensers consist of two or more strips of metal foil separated by thin sheets of mica. The complete unit is pressed into compact (usually plastic) form. Mica condensers are of the fixed and variable variety. The fixed types are used as r-f bypassing and coupling and range in values from 10 to 5000 micro-micro farads (10 $\mu\mu\text{f}$ to 5000 $\mu\mu\text{f}$).

The variable types are commonly called trimmers and padders and are used for circuit aligning or peaking and have values ranging from 1 to 1000 micro-micro farads (1 $\mu\mu\text{f}$ to 1000 $\mu\mu\text{f}$).

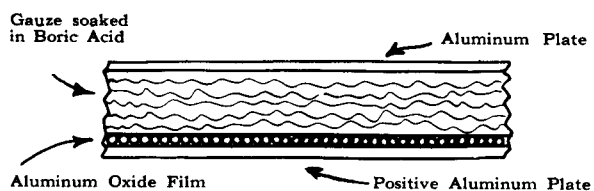


Fig. 16. Section of an electrolytic condenser.

Electrolytic (wet and dry) is a high capacity condenser used in the plate or high voltage filter supply. One plate of these condensers consists of sheets of aluminum or aluminum alloy on which a thin insulating film of aluminum oxide is formed by connecting the plate to a positive d-c voltage. This electrode is immersed in a liquid electrolyte in a "wet" type of condenser, the electrolyte actually serving as the other "plate," to which a conductive connection is made by a second aluminum electrode immersed or holding the electrolyte. The latter electrode is negative. The electrolyte is usually a solution of borax and boric acid. The "dry" type of electrolytic condenser is similar, but has its electrolyte soaked in a strip of gauze separating the filmed and non-filmed electrodes. In both types the thin film is the dielectric which, together with the relatively large plate area, gives this type of condenser a very high capacitance in a small space.

There is an important difference, however, in the electrolytic condenser and the other fixed condensers described previously, that is, the plate on which the film is formed must be maintained always at a positive potential in respect to the other electrode. Thus this type of condenser can only be used in circuits with steady or pulsating d-c applied to the terminals.

Both the "dry" and "wet" electrolytic types are available to be used on voltages up to 500 volts and range in capacity from 4 μf to 100 μf or more.

If an a-c voltage or a wrong polarity is placed on an electrolytic capacitor the dielectric film is destroyed and the capacitor will pass a high leakage current.

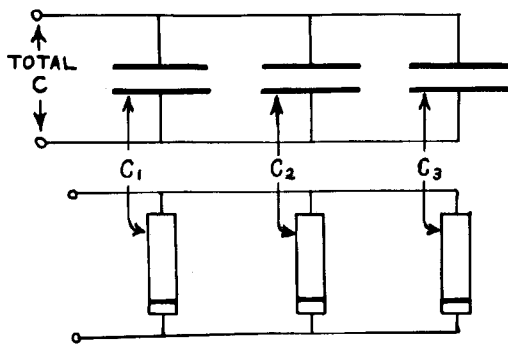


Fig. 17. Condensers in parallel.

CONDENSERS IN PARALLEL

When condensers are connected in parallel the effect is to produce a condenser with plates of a larger total surface area. Since the capacitance is proportional to the surface area of the conducting plates, the total combined capacitance is equal to the sum of the individual capacitances connected in parallel. This may be stated as:

$$C = C_1 + C_2 + C_3$$

where C = resultant capacitance
 C_1, C_2, C_3 are the individual capacitances.

This fact is made use of in actual practice in mak-

ing up condensers of odd capacities by connecting several condensers of standard size in parallel.

With condensers connected in parallel, the voltage rating of the combination is limited by the safe working voltage rating of the lowest voltage condenser in the circuit.

CONDENSERS IN SERIES

When condensers are connected in series, the effect is to produce a single condenser with a dielectric of a greater thickness. Since the capacitance is decreased as the thickness of the dielectric is increased, the total combined capacitance is less than that of the smallest of the individual capacitances. This increase in thickness of the resultant dielectric thickness makes the series combination able to withstand higher voltages without breaking down the dielectric.

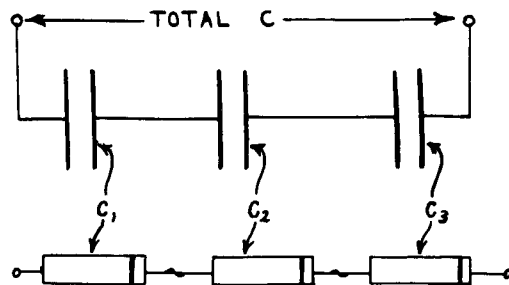


Fig. 18. Condensers in series.

The resultant of series capacities is found by:

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

where C = resultant capacitance
 C_1, C_2, C_3 are the individual capacitances.

Condensers of medium voltage rating are often connected in series to give a resultant capacitor that will withstand higher voltages. The resultant voltage rating of the condensers connected in series does not add directly unless the condensers in series are of the same type, capacity and voltage rating.

To better understand the function of condensers and inductances in a d-c electrical circuit, the water system is again used as an analogy in Fig. 19.

The water from the pump comes in surges. Three flexible diaphragms with small openings, A, B, C, represent the inductances. Three storage spaces, 1, 2, 3, represent the condensers.

When a surge of water comes from the pump and strikes the diaphragm A, all cannot get through the small opening at the rate it comes from the pump and is held back. This then flows into storage space 1. When the surge stops, the flow through the diaphragm is maintained by the emptying of the storage space 1. With additional duplicate operations, the water coming from the end of the pipe will flow with a steady stream despite the fact that the pump supplies only surges.

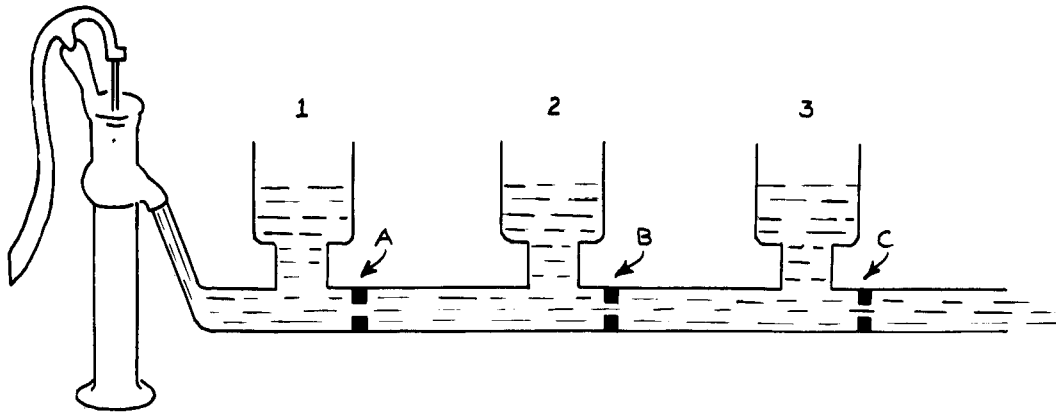


Fig. 19. Inductance and Capacitance compared to a water system

REVIEW QUESTIONS

1. What is the practical unit for capacitance? Its abbreviation?
2. When a condenser is inserted in an electrical circuit, is the current flow through the capacitor maximum instantly? The voltage across the condenser?
3. What constructional types of condensers are found in radio receivers?
4. Should electrolytic condensers be used in a-c or d-c circuits? Why?
5. Is the total capacity greater or less when condensers are connected
 - a. Series?
 - b. Parallel?
6. Explain in your own words the functions of inductances and condensers in a d-c circuit in which the current and voltage at the source are not constant in value?

ALTERNATING CURRENT THEORY

ALTERNATING CURRENT

In the previous pages, we have only considered current which flows in one direction continuously. However, since an alternating current is so very important in the operation of the radio and its effects on the circuit are so different from those of d-c, it is very important to know and understand what causes these peculiar effects.

Alternating voltages and currents periodically reverse their polarity and direction according to a definite symmetrical curve, called the sine wave.

When an alternating current has passed from zero to maximum in one direction, died away to zero, risen to a maximum in the other direction, and gone back to zero again, it has completed one cycle. The frequency of an alternating current is the number of complete cycles which take place in one second.

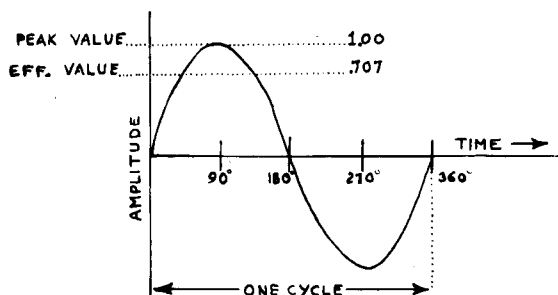


Fig. 20. Sine-wave representing one cycle of alternating current or voltage.

The frequencies of alternating current in radio circuits vary from forty per second to several million. Currents which alternate at a frequency of 20,000 cycles per second or more are called radio frequency currents. Radio frequency current travels on or near the surface of a conductor. Low frequency and direct currents travel through the body of the conductor. A metal pipe will conduct high frequency currents as well as a solid metal rod of the same diameter. Under proper conditions radio frequency currents will surge or oscillate back and forth in an open circuit or single wire.

Those frequencies which will produce sounds in our ears are known as audio frequencies. There is no sharp dividing line between the radio frequencies and the audio frequencies, but it may be broadly stated that the audio frequencies are those of a frequency from 16 to 16000 cycles per second.

In a-c, the current and voltage through a circuit do not always reach a maximum value at the same instant. The difference or displacement between the current and voltage is called phase displacement and is measured in electrical degrees. One electrical degree is $1/360$ of a complete cycle. As will be seen later, the current taken by an inductance lags the voltage by 90 electrical degrees, while the current taken by a condenser leads the applied voltage by 90 electrical degrees (Fig. 21).

A-C CIRCUIT RESISTANCE

If an a-c voltage is applied to a resistance, an alternating current will flow through the resistance in phase with the voltage and will behave the same as in a d-c circuit. The relation of the voltage and current at any instant can be expressed by Ohm's law: $I = E/R$.

INDUCTIVE REACTANCE

In d-c, it has been shown that a coil retards a change in current. Likewise, when an impressed a-c voltage is applied across the terminals of an inductance, the current is not only opposed by the resistance of the coil but also by the self-induced voltage. Self-induced voltages therefore act like resistances and the effect is equivalent to a certain number of ohms resistance which would have the exact same effect. This effect of self-induction is called inductive reactance.

A given wire has the same resistance whether it is straight or coiled up. However, the reactance of a wire increases immensely if it is coiled up and also increases if a good magnetic path such as iron is provided in its magnetic field. The resistance of a wire at low frequencies is independent of frequency but the reactance increases in proportion to the frequency.

CAPACITIVE REACTANCE

In direct current a voltage applied would cause a sudden charging current, but that was all. However, in alternating current, a voltage will result in the condenser becoming charged first in one direction and then in the other — this rapidly changing charging current being the equivalent of an alternating current through the condenser.

In a d-c circuit, the current was shown to come to a maximum value before the voltage and therefore it was termed a "leading current." Likewise, if an a-c voltage is impressed across a condenser, it can be shown that the current leads the voltage, just opposite to the condition found in an inductance.

Since a condenser does not allow a current to flow with perfect ease, it impedes a current in the same manner as in inductance. The word capacitive reactance is used to describe this effect in circuits with condensers.

A condenser offers greater resistance to a flow of current of low frequency. This is to be expected as the plates of a condenser at high frequencies are being charged and discharged more often resulting in a greater apparent current flow. This means that there is less reactance at high frequencies.

In a-c circuits using inductance or capacity, the current and voltage are not in phase and Ohm's law is no longer valid. In d-c circuits the current is limited by the resistance, whereas in a-c circuits a property called reactance must be considered. Reactance in a capacity is the effect of the capacity in opposing any voltage change; in an inductance it is the effect of the opposition to any current change. Where only reactance is found in an electrical circuit, energy is not consumed, since the energy in

the electrostatic field and the electromagnetic field is returned to the circuit. Practically, perfect inductance and capacity units do not exist. Consequently, some energy is consumed in the resistive element of the units.

At a given frequency, the current that will flow in a circuit will be proportional to the applied voltage with a given reactance. Reactance is expressed in ohms, the same unit used to express resistance.

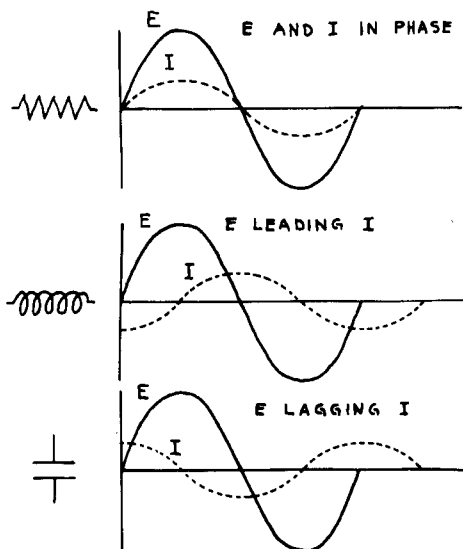


Fig. 21. Current and voltage relations in a-c circuits.

A-C IMPEDANCE

Since all wire has resistance, it is necessary to know how to combine resistance and reactance for the calculation of impedance in a-c circuits. The combined effect of resistance and reactance in a circuit is called impedance. For series connections

$$Z = \sqrt{R^2 + X^2}$$

where R is the resistance and X is the reactance. The terms Z , R and X are all expressed in ohms. Ohm's law for alternating current circuits then becomes

$$I = \frac{E}{Z}; \quad Z = \frac{E}{I}; \quad E = IZ$$

RESONANCE

It has been shown that the inductive reactance of a coil and the capacitive reactance of a condenser are oppositely affected with frequency. Inductive reactance increases with frequency while capacitive reactance decreases as the frequency is increased. In any combination of the two, there is therefore one particular frequency where the values of inductive and capacitive reactances are equal, the difference between them is zero, making the impedance equal to the resistance of the circuit. The frequency at which this condition occurs is called the resonant frequency of the circuit and the total opposition to the current flow is simply equal to the resistance of the circuit.

A resonant circuit is sometimes compared to a flywheel in its behavior, since a flywheel will continue to revolve after the driving power is removed. A resonant circuit will also continue to oscillate

when the driving power is removed and this is sometimes called "the flywheel effect." The flywheel continues to rotate due to the mechanical energy stored, and an electrical resonant circuit due to the energy stored in magnetic fields of inductances and electrostatic fields of condensers.

SERIES RESONANCE

In series circuits, resonance occurs when the inductive reactance is equal to the capacitive reactance and the only opposition to the current flow is the resistance of the circuit.

In most practical series resonant circuits, the resistance of the coil largely determines the circuit resistance. A condenser may be considered as having pure reactance, but a coil has resistance and in resonant circuits this must be considered. In well designed inductances at low frequencies, up to a few thousand cycles, the a-c coil resistance will not be much greater than the d-c resistance. However, at radio frequencies the a-c resistance may be several times the d-c resistance, due to the skin effect of wires. This is because the high frequency currents travel only over the surface or "skin" of the wire, thus making only a small proportion of the total cross section area of the wire effective in carrying the current, thus increasing the resistance to the flow of current.

QUALITY FACTOR OR "Q" OF COILS

The quality of a coil at resonant frequencies is expressed by a factor "Q" which is defined as the ratio of reactance to resistance at a specified frequency.

$$Q = \frac{X_L}{R} \quad \frac{\text{(Inductive reactance)}}{\text{(Resistance)}}$$

Fortunately, the value of Q is usually fairly constant over a band of frequencies in the radio frequency range because R increases due to skin effect nearly as fast as X_L .

The high Q coils are actually "low-loss" coils and are in the order of 100 to 300. The Q is limited by the size, shape, conductor, and form material of the coil. The larger the conductor and size of a coil, the better the Q for a given inductance value.

SERIES TUNED CIRCUITS

A typical application of series tuned circuits is shown in Fig. 22, which represents the tuned grid circuit of an r-f or i-f circuit. It might be supposed at first thought that this is a parallel circuit, but this is not so. The voltage in the tuned circuit is induced in the winding of the secondary coil and should be considered in series with the winding.

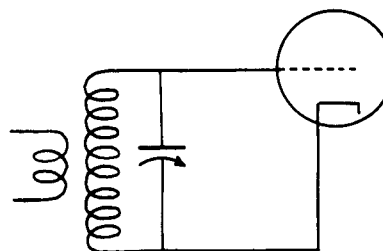


Fig. 22. Series tuned circuit.

PARALLEL RESONANCE

In many circuits used in radio work the inductance is connected in parallel with the capacitance across the source of voltage. This arrangement forms a parallel tuned circuit, the effects of which are very different from those for the series resonant circuit.

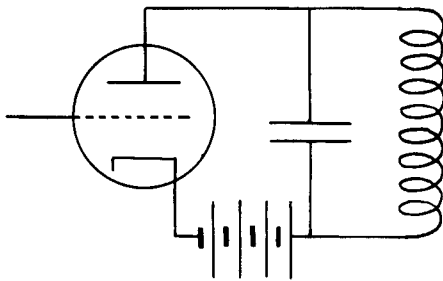


Fig. 23. Parallel tuned circuit.

In series circuit, the minimum impedance was equal to the coil resistance. In a parallel circuit, the lower value of the coil resistance R , the greater will be the resonant impedance.

Parallel resonant circuits are used particularly in plate circuits of vacuum tubes because of the high resonant impedance necessary for high amplification in voltage amplifiers such as i-f amplifiers, etc. This circuit allows plate current to be supplied the tube through the coil. The secondary circuit may be the grid circuit of the next tube.

The voltage at resonance is maximum across either the inductance or capacity in a series connected circuit, and is equal and opposite in polarity across each branch.

In a parallel circuit, the impedance, and therefore the voltage, is maximum across the circuit at resonance. In both cases the magnitude of the voltage is governed by the resistance in the circuit, so that the measured voltage is equal to the applied voltage times the Q factor for the resonant circuit.

REVIEW QUESTIONS

1. Describe the difference between d-c and a-c.
2. What determines the frequency of an alternating current?
3. Are the current and voltage in an a-c circuit always at maximum or minimum value at the same time?
4. What is the phase of current and voltage in a resistance circuit?
5. What term is used to denote the effect of inductance in an a-c circuit?
 - a. Condenser?
6. Is a condenser of given value more effective at lower or higher frequencies of a-c?
7. What unit is used to denote the measured effect of condensers and inductances in a-c circuits?
8. How can Ohm's law be used in a-c circuits?
9. Explain the difference between capacity and inductance with respect to current and voltage in an a-c circuit in terms of electrical degrees.
10. Is resistance ever found in a-c circuits without a resistor? Where?
11. What condition would exist, when the effects of an inductance and condenser used together in an a-c circuit, were equal and opposite?
12. What connection is there between an electrical circuit and a mechanical flywheel?
13. Symbolically draw a single inductance and condenser in
 - a. Parallel circuit.
 - b. Series circuit.
14. What abbreviated term is used to denote the quality of a resonant circuit?
15. What chiefly governs the quality of a resonant circuit?
16. What two main effects would result in a resonant circuit of poor quality?
17. Is the a-c voltage greater or less than the applied voltage across
 - a. Parallel tuned circuit?
 - b. Series tuned circuit?

ELECTRON TUBE THEORY

VACUUM TUBES

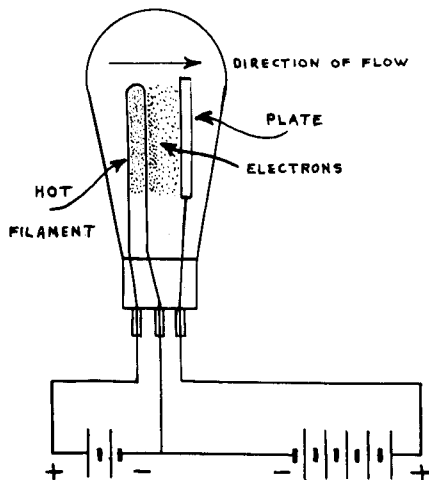
The thermionic vacuum tube has probably been the most important single invention in the development of radio, for with it the whole field of electronics was opened. There are seemingly an endless number of tasks which are being found every day for its use.

ELECTRON EMISSION

Even though there are free electrons in a substance and they are constantly in motion, they cannot escape from the substance of their own motion. However, it is possible to impart sufficient speed and energy to the electrons of many substances to make them be emitted from the body. As soon as an electron is emitted, the unbalanced electrical force will attract it back to the substance unless an outside voltage source is used to attract it.

There are many ways of driving electrons out of a substance; however, the easiest is by means of heat applied to the substance. Emission of electrons caused by applying heat to a body is called thermionic emission, and the body which emits the electrons is the cathode or filament, while the body to which the electrons are attracted is the plate or anode.

There are two types of electron emitters: one the filament type which is used in rectifiers, battery receiver tubes and sometimes in tubes that are heated by low a-c voltages; the other type is the indirectly heated cathode such as is used in most tubes intended for operation from the a-c power line.



When cathodes are used, the filament is referred to as the heater, since its only purpose is to heat the cathode and not operate as an electron emitter.

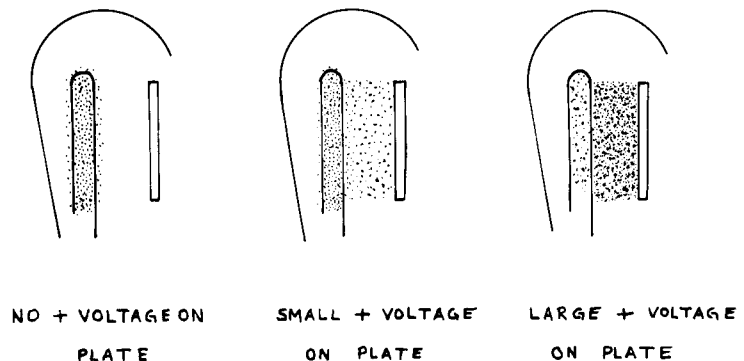
DIODES OR TWO-ELECTRODE TUBES

The simplest and first tube to be used in radio was a diode or two-element tube, having a filament and a plate as shown in Fig. 24. To explain this operation we will connect a battery across the filament for heating purposes, then apply a positive potential to the plate through a switch. When the

switch is open there is no charge on the plate and the filament is heated, the filament will emit electrons and form a miniature cloud surrounding it. However, since they are all charged negatively, the electrons will return to the filament. This is due to the fact that negative charges of electrons in the space around the filament form a strong negative charge called the "space charge," which repels the electrons back to the filament.

If now we close the switch and apply a small positive potential on the plate in respect to the filament, a steady stream of electrons will be attracted from the filament to the plate, causing a current flow around the circuit. If a stronger potential is applied to the plate more and more electrons will be attracted from the filament until the saturation point is reached. If we reverse the plate potential by making the plate negative no electrons will be attracted and therefore no current will flow. If an alternating voltage is applied to the plate the plate is alternately made positive and negative. The plate current flows only during the time when the plate is positive, hence the current through the tube flows in one direction and is said to be rectified. Diode rectifiers are used in receivers to convert a-c to d-c for supplying "B" and "C" voltages and also for rectifying r-f voltages as a detector.

Fig. 24. One battery is used only to heat the filament to a temperature where it will emit electrons. The other battery places a positive potential on the plate, with respect to the filament, and the electrons are attracted to the plate. The flow of electrons completes the electrical path, and current flows in the plate circuit.



SATURATION CURRENT

Beyond a certain plate voltage for a given filament temperature, additional plate voltage has little effect in increasing the plate current. The reason is that all the electrons emitted by the cathode are already being drawn to the plate or the plate attracts the electrons at the same rate that they are emitted. However, if we raise the filament temperature, or increase its area and keep the temperature the same, we can increase the number of electrons emitted and then a higher plate voltage will cause a greater current flow. For this reason heavy duty rectifier and power tubes have heavy filaments which require considerable power to heat them.

Tube performance can be easily understood by graphic means referred to as tube characteristic curves (refer to curve for diode rectifier, fig. 25). In the simple diode rectifier curve, it can readily be seen that as the voltage applied to the plate increases the plate current also increases while the cathode is maintained at a constant temperature. It can also be seen that at zero plate voltage, the plate current cuts off, while at some value of plate voltage plate current saturation occurs.

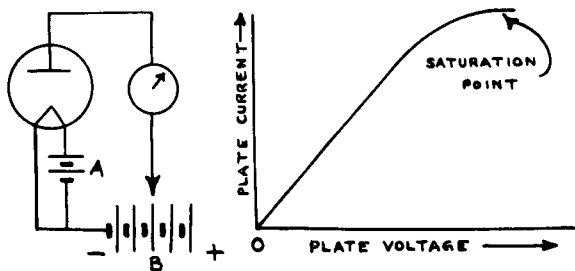


Fig. 25. The diode or two-element tube and a typical characteristic curve.

Power consumed in the tube is dissipated in heat as in any resistance circuit and is also the product of the plate current and plate voltage.

TRIODE VACUUM TUBES

It is apparent from the operation of the diode tube that it can simply adapt itself in conducting current in one direction only and cannot be used to amplify a signal. The vacuum tubes which amplify signals, require a controlling element called the grid, which acts as a valve for controlling the flow of electrons from cathode to plate or anode. The three-electrode tube is the two-element tube with the addition of a grid in the form of a wire screen or grouping of fine wires placed between the filament and the plate. In practice the filament is surrounded by the grid and the grid is surrounded by the plate, which allows electrons emitted from all sides of the filament wire and attracted by the plate to flow through the open space in the grid screen or winding. By placing this third electrode or grid between the filament and plate so that the electrons must go through the open spaces in it on their way to the plate, then by varying the potential of this third electrode, the electron flow can be controlled. Since the grid is close to the filament and in the midst of the space charge, when it is made positive by means of a signal or battery, it tends to neutralize the effect of the space charge and reducing this opposing force it makes it easier for the electrons to get to the plate. This increases the electron flow and the resultant plate current.

When the grid is made negative the grid assists the space charge in repelling more of the emitted electrons back to the cathode, causing fewer electrons to get to the plate, and consequently the plate current to decrease. As the grid voltage is made more and more negative the plate current becomes smaller and smaller until it reaches zero. Hence, when the voltage on the grid is varied in accordance with a signal, the plate current varies with the signal. Because a small voltage applied to the grid can

control a comparatively large amount of plate current, the signal is amplified by the tube.

CHARACTERISTICS OF TRIODES

The important feature of vacuum tubes with more than two elements from the standpoint of voltage or power amplification is the control of the plate current by grid voltage. The grid in a sense varies the resistance of tube (plate resistance) because it varies the number of electrons or current that flows to the plate for a given applied plate voltage.

The grid, in triode tubes, does not require current in most radio circuits. A negative bias voltage is connected in series with the grid and the applied signal voltage should have a peak value less than this bias potential in order to prevent the grid voltage from becoming positive. If the grid does become positive, electrons will flow to the grid just as they do to the plate. In any electrical circuit, the resistance is defined by the flow of electrons or current for a given applied voltage. Therefore, the grid has a certain value of resistance when it is positive and an infinite resistance when it is negative. It acts exactly like the diode in this respect.

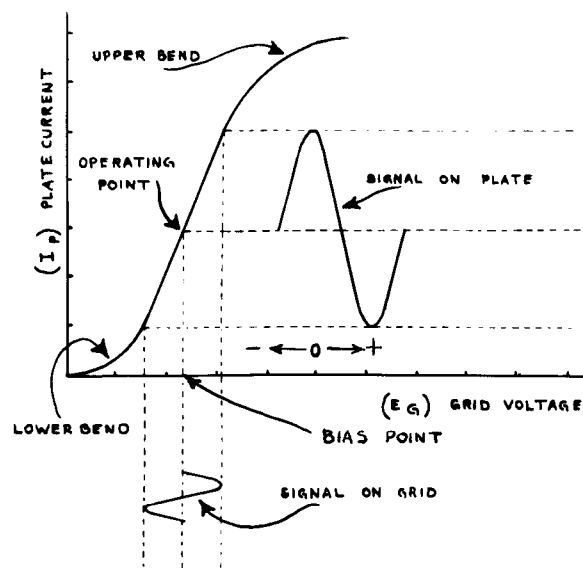


Fig. 26. Operating characteristics of a vacuum-tube amplifier. Class-A amplifier operation is depicted.

Referring to Fig. 26, the operating point on the characteristic curve is determined by the relationship between the varying grid voltage and plate current. In choosing an operating point, the type of service the tube is to perform will be the governing factor. Fig. 26 is a graph of the operation of the vacuum tube. The variation in plate current, with voltage on the plate held constant, is represented by the sloping line. It will be noticed that the grid voltage ranges in the negative direction from a value enough to reduce the plate current to zero to a value slightly in the positive direction. Grid voltage is spoken of as the voltage between grid and cathode or filament. A portion of the sloping curve is seen to be essentially a straight line (linear). This linear portion falls between the two bends, the top bend curving toward plate saturation and the bottom one toward

plate current cut-off. The variation in plate current is proportional to the variation in grid voltage in the straight portion of the curve in the region between the two bends. By adjusting the grid voltage (bias) the plate current can be set to any desired level.

Tube characteristic curves are used to show two operating conditions, one called the static, the other dynamic. The static characteristic curve shows the value of plate current that will flow with some particular value of grid and plate voltage with no loading device in the plate circuit. The dynamic characteristic curve also shows the value of plate current that will flow with some particular value of grid and plate voltage, but with loading device in the plate circuit, thus representing the actual operating conditions of the tube.

Fig. 26 shows a grid bias value which places the operating point in the middle of the linear region. If an alternating voltage were applied to the grid this voltage would be considered in series with the direct voltage applied to the grid as bias. This alternating voltage would swing the grid more and less negative from the mean value of bias voltage, and the plate current would swing up and down about the mean value of plate current. It can be seen that the plate current change would be proportional to the grid voltage change and therefore the wave shape of the plate current will be an enlarged or amplified replica of the grid wave shape. If, however, the grid voltage swing is large enough to force the plate current to values in the upper or lower bend region of the curve, the plate current wave would no longer look like the grid wave, and when this occurs, distortion takes place. If the operating point is set near the upper or lower bend region, plate current changes will be in the linear portion during one-half or a portion of a cycle. When a tube is adjusted to operate in the bend portion of the curve the output wave-form is a distorted variation of the input or grid wave-form. Tubes are often used in circuits to operate on the non-linear portion of the curve to obtain some specific result, but when distortion is to be avoided the tubes should only operate linearly.

The load connected in the output or plate circuit is termed the load impedance or load resistance. The output load is the device which utilizes the work done by the tube. In radio circuits the loading is usually in the form of a resistance, inductance or tuned resonant circuit. When the load is a resonant circuit, as shown previously (fig. 23), the reactances cancel at the resonant frequency and the load is purely resistive at this one frequency. Above and below the resonant frequency the load again becomes reactive, capacitively above resonance and inductively below resonance.

AMPLIFICATION

The amplification or the ratio of the output voltage to the input voltage is dependent on two conditions. The first is the *amplification factor* ($m\mu$) or the amount the tube itself steps up or amplifies the grid voltage. This amplification factor (μ) cannot be fully used due to the internal plate resistance of the tube. The second factor is the effect of the internal tube or plate resistance and the associated

plate load impedance. When these effects are combined we can obtain the effective amplification of a tube under specific circuit conditions.

The ratio of the alternating voltage applied to the grid circuit to the alternating voltage obtained in the output circuit is the voltage amplification of the amplifier (gain).

The ratio of output power to a-c power consumed in the grid circuit is called the power amplification of the amplifier.

INTERELECTRODE CAPACITANCE

The grid, plate and cathode of a triode form a capacitance between each other, each electrode acting as a plate of a condenser as shown in Fig. 27a. The capacitances are those existing between grid and plate, plate and cathode, and grid and cathode. These capacitances are called interelectrode capacitances. The presence of the grid-plate capacitance is the most objectionable as it transfers energy through the tube in a direction opposite to that desired. In high gain r-f or i-f amplifier circuits this capacitance will produce undesired coupling between the input and output circuit which will cause instability and oscillation.

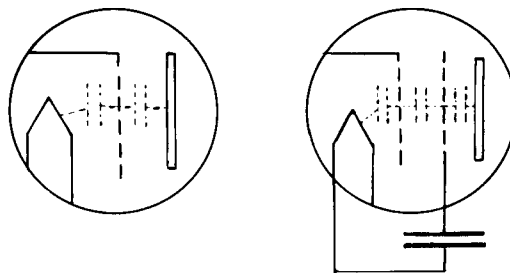


Fig. 27a Fig. 27b
Fig. 27. Inter-electrode capacities within tubes.

Energy from the plate circuit can be coupled or fed back by a process called feedback to the grid circuit to be reamplified. When the voltage fed back to the grid is in phase with the applied signal voltage, the feedback is considered as positive. This positive feedback voltage will reinforce the applied signal voltage thereby increasing the amplification. Positive feedback is usually termed regeneration or positive regeneration, and when there is enough positive feedback to overcome grid circuit losses, oscillation occurs. When the voltage fed back to the grid from the plate is out of phase with the applied signal voltage, the feedback is considered as negative. This negative feedback voltage will produce the opposite effect of positive feedback and will reduce the effective grid voltage thereby reducing the amplification. Negative feedback is also called degeneration or negative regeneration.

TETRODES

The capacitance between the grid and plate in a tube can be made small by the addition of another electrode in the tube called a screen. This four-electrode tube is called a tetrode. The screen is mounted between the grid and plate and acts as an electrostatic shield between them, thus greatly reducing the grid-plate capacitance. The effectiveness of this shielding action is increased by connecting a by-pass

condenser from this screen to cathode. The capacity then divides as shown in Fig. 27b. Instead of the plate having capacity to grid, the capacitance is now to ground or cathode, which is of small consequence in the actual circuit.

The screen has another desirable effect in that it makes the plate current practically independent of plate voltage over a certain range. The screen in practice is connected to a positive voltage which attracts electrons from the filament. But because of the comparatively large space between wires of the screen, most of the electrons drawn to the screen pass through it to the plate. At the same time the screen shields the electrons between cathode and screen from the plate so that the plate exerts very little electrostatic force on attracting the electrons near the cathode. Hence plate current in a screen grid tube depends a great deal on the screen voltage and very little on the plate voltage provided the plate voltage is higher than the screen voltage. In view of the plate current being largely independent of plate voltage, it is possible to obtain much higher amplification with a tetrode than with a triode. Likewise this higher gain can be used without the plate grid capacity instability inherent in triodes at radio frequencies.

PENTODES

Electrons may be liberated from a metal other than through heating, by the bombardment of the metal by a stream of electrons. This is called secondary emission. In a vacuum tube the electron stream striking the plate will cause considerable secondary emission from it. In two or three electrode tubes, this does not cause trouble because no positive electrode other than the plate is present to attract them. In the case of the tetrode, the presence of the screen close to the plate causes the secondary electrons to flow from plate to screen in the opposite direction to the cathode-plate electron flow, thus lowering the plate current and permissible plate swing. This effect is particularly noticeable if the plate voltage swings down to a value lower than the screen voltage.

This secondary emission is removed if a fifth element, known as the suppressor grid, is inserted in the tube between the screen and plate. By connecting this element to the cathode, the negative potential in respect to the plate repels the secondary electrons and returns them to the plate where they cannot cause trouble. The common name for the five-element tube is the pentode.

Pentodes are utilized as high power output tubes and for high voltage amplification. In power output pentodes, the suppressor makes possible a large power output with high gain, due to the fact that the plate swing can be made very large. In r-f amplifiers the suppressor permits high voltage amplification at moderate values of plate voltage. The plate voltage may run even lower than the screen voltage without serious loss of gain. Such tubes are the 6K7, 6B7 and 6J7.

BEAM POWER TUBES

The beam power tube is a modification of the pentode in that it uses a different means of suppressing the secondary emission. In this tube there are four elements — cathode, grid, screen, and plate so

spaced that the secondary emission is suppressed without an actual suppressor. The beam forming plates and spacing of electrodes make the electrons slow down to almost zero velocity in the region between plate and screen when the plate voltage is low. In this region and under this condition, the electrons form a negative cloud or space charge which repels the secondary electrons and returns them to the plate

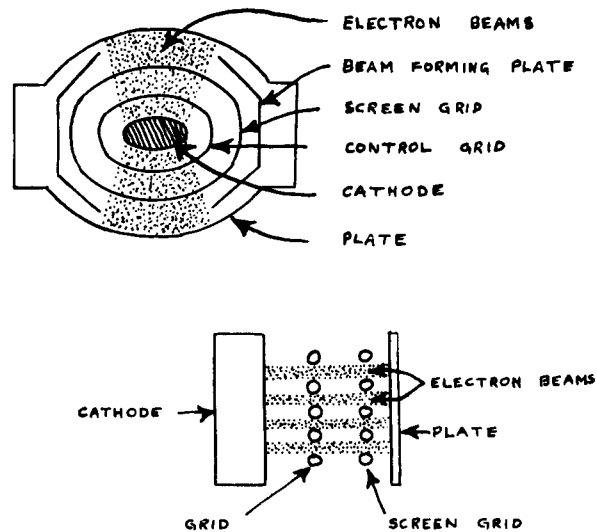


Fig. 28. Details of beam tube.

Another feature of this tube is the low current drawn by the screen. The screen and grid are spiral wires wound so that each turn of the screen is shaded from the cathode by a grid turn. This alignment of screen and grid causes the electrons to travel in sheets between the turns of the screen so that very few of them flow to the screen. Because of the effective suppressor action and the low current drawn by the screen, the beam power tube has high power output, high power sensitivity and high efficiency. The 6L6 is a beam power tube.

VARIABLE MU PENTODES

While it is desirable that audio tubes have linear characteristic in order to keep the audio distortion low, the r-f and i-f tubes are intentionally made with non-linear characteristics, in order to obtain a-v-c or automatic volume control action. Since many of the station signals impressed on the first tubes of the receiver vary from $2 \mu\text{v}$ to a possible 500 millivolts, the overall gain of the receiver needs adjusting near to a million times to keep the output signal constant. A large part of this variation is automatically taken care of by the a-v-c.

The ordinary pentode tube has a relatively sharp cut-off of plate current as the negative grid voltage is increased. With a cut-off at about 2 volts for the sharp cut-off tube this does not afford very much control and on high negative swings of the grid voltage the tube plate current would be zero. Variable-mu tubes have a rapid decline of plate current for the initial increase in bias, then a slow decrease in plate current for higher values of negative bias so that the plate current gradually approaches zero current for high values of negative bias voltage.

Ordinary tubes give rise to severe distortion in the region of plate current cut-off. The variable- μ tubes are so designed that very little distortion results, for any input signal in the operating range. Variable- μ tubes are also referred to as remote cut-off tubes, since the plate current cuts off at some remote grid bias.

Class "A" Amplifier — One operated such that tube or tubes are biased so as not to draw grid current on positive grid swings nor cut off plate current on negative grid swings.

Class "B" Amplifier — One operated such that tube or tubes undergo plate current change only during most or all of the positive half of the cycle of the grid swing. Class "B" amplifier draws grid current and must be supplied power from preceding stage. With no signal, very little plate current flows.

Class "AB" Amplifier — One operated as a combination of "A" and "B". On low outputs it operates class "A", on high outputs nearly class "B"

Class "C" Amplifier — One operated such that plate current changes occur only during a fraction of the grid swing. Grid is biased beyond plate current cut-off point during no signal periods. Used only at radio frequencies.

Letter Symbols for Vacuum Tube Notation

Grid potential	E_g, e_g
Grid current	I_g, i_g
Grid conductance	g_g
Grid resistance	r_g
Grid bias voltage	E_c
Plate potential	E_p, e_p
Plate current	I_b, I_p, i_p
Plate conductance	g_p
Plate resistance	r_p
Plate supply voltage	E_b
Emission current	I_s
Mutual conductance	g_m
Amplification factor	μ
Filament terminal voltage	E_f
Filament current	I_f
Grid-plate capacity	C_{gp}
Grid-cathode capacity	C_{gk}
Plate-cathode capacity	C_{pk}
Grid capacity (input)	C_g
Plate capacity (output)	C_p

REVIEW QUESTIONS

1. Can electricity flow through a vacuum? How?
2. Name two factors that will govern the current flow in a diode tube.
3. How will the current flow be affected if an a-c voltage is applied to the plate of a diode tube?
4. What is accomplished by placing a grid between the cathode and plate of a diode tube?
5. How does this grid affect the plate current flow?
6. Can the grid affect unlimited changes in plate current? Explain.
7. If the plate current wave form is to be a replica of the grid wave form, what must be avoided in the operating characteristics of the tube?
8. Under what conditions are these characteristic curves made:
 - a. Dynamic.
 - b. Static.
9. Why does a tube usually have a load circuit?
10. What is distortion?
11. What is the main function of tubes other than rectifiers?
12. What is the purpose of
 - a. Screen grid?
 - b. Suppressor grid?
13. Why is a "Beam Tube" so called?
14. What is a "remote cut-off" tube?
15. Could a single tube be used as "Class B" to amplify audio frequencies with a minimum of distortion? Explain.

RADIO COMMUNICATIONS SYSTEM

THE TRANSMITTED RADIO SIGNAL

In the transmission of music or voice between the broadcast station and the radio receiver it is not enough simply to generate radio frequency power continuously and radiate it from an antenna. Something must be done before the waves are transmitted to make them carry the messages we wish to convey. The process of applying this intelligence to the transmitted wave is called modulation. In Fig. 29 is

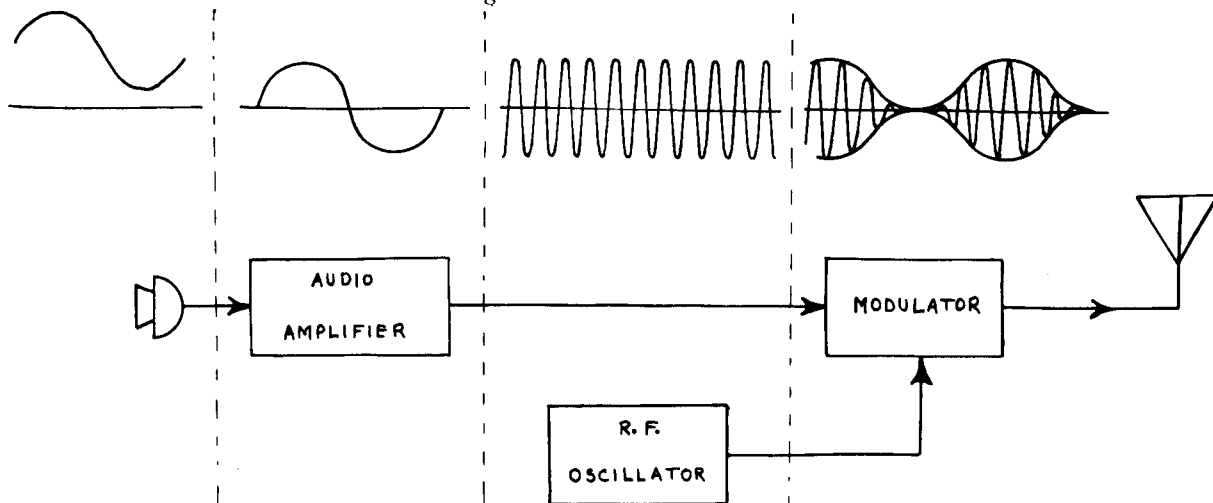


Fig. 29. Wave forms of an amplitude modulated transmitter.

shown a simple sketch of the audio signal and r-f oscillator signal being combined in the modulator to form the transmitted signal. In Fig. 30 is shown a carrier which is modulated by a simple a-c voltage starting at point X. In reality this modulated wave

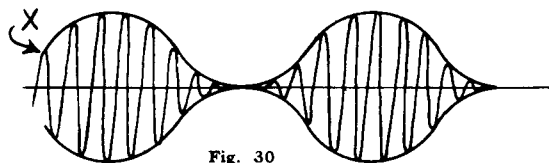


Fig. 30

would contain components of at least three radio frequencies. These would consist of the sum and difference of the original frequency and the modulation frequency. These additional frequencies are called the sideband frequencies while the original frequency component is called the carrier. For example, the carrier frequency of a station operates at 600 kc and is modulated by a 5000 cycle audio signal; the sum and difference frequencies are 605 kc and 595 kc respectively; the carrier frequency, of course, is 600 kc.

The degree of modulation or loudness of the audio signal is the ratio of the audio signal in a-c volts to the carrier amplitude a-c volts.

CARRIER FREQUENCY BANDS FOR HOME RECEIVERS

Radio communication frequencies run from approximately 20 kc to several hundred megacycles. Of this wide range only a small part is used in home receivers and reception is limited to modulated signals having entertainment value. Of course broad-

casting frequencies from 540 kc to 1600 kc are the most important and constitute the minimum coverage for home entertainment. As we will learn later, the variable capacitor which tunes the receiver determines the maximum number of frequencies which we can tune in one band. This capacity therefore settles the tuning ratio for higher frequency bands also, except for special band spread circuits. The following is a list of the useful bands for home receivers:

Name	Band Coverage	Communication Services
Long Wave	"A" 140- 410 kc	Aircraft, Weather Report
Broadcast Police Aircraft	"B" 530-1700 kc	Broadcasting Stations, Police, Aircraft, Amateur
Amateur	"C" 2000-6000 kc	Amateur
Short Wave	"D" 6000- 21 mc	Amateur, Trans-ocean Telephone, Ship-to-Shore
Ultra Short Wave	"E" 21 - 70 mc	Short Wave Broadcast, Police, Television Sound Transmitters, Amateur, F.M.

REQUIREMENTS FOR A HOME RECEIVER

There are three requirements which must be fulfilled for obtaining intelligence from a modulated broadcast carrier wave. These are:

1. Carrier Selector or r-f tuning unit.
2. Detection.
3. Audio Reproduction.

To elaborate on these requirements, the modern receiver must be able to:

1. Separate the signals of any station it is desired to hear from those of all other stations. The ability of a receiver to select the wanted from the unwanted signal is called the selectivity.

2. Amplify the incoming weak signals with sufficient energy to operate the loudspeaker as loudly as desired.

3. Detect and amplify the audio or sound waves from the station modulated carrier with no distortion.

4. Reproduce by a loudspeaker the received signal so that it sounds as near like the original studio pick-up as possible.

There are two popular types of receivers used for the home reception of broadcast programs which fulfill the above requirements. They are the Tuned r-f receiver and the superheterodyne receiver.

THE TUNED R-F RECEIVER

In the tuned r-f receiver, one or more variable tuned amplifier stages are adjusted by a single dial to the different frequencies of the stations it is desired to receive. For the broadcast band the r-f tuning circuits must be adjusted so as to tune to any frequency between 540 kc to 1600 kc. The signal voltage (r-f carrier with modulation) is impressed in the antenna circuit; is amplified with no change in shape by the r-f amplifier; is detected or converted to an audio frequency at the detector; audio is amplified by one or two stages of audio amplification, the output of which supplies energy to the loudspeaker. This system is shown in simplified form in Fig. 31. It is important to remember that this tuned r-f system amplifies the signal at its own carrier frequency. There are drawbacks to this type of sys-

tem in that it is difficult to design an r-f amplifier which will give a gain of more than 40 per stage at the broadcast frequencies. This necessitates the use of many stages if high sensitivity is to be obtained. Also, since the primary of each r-f transformer induces a higher voltage into the secondary at the higher frequencies than at the lower ones, due to

SUPERHETERODYNE

cannot be built with as great efficiency as they would have if designed to work at one single fixed frequency.

In the superheterodyne circuit instead of selecting and amplifying the r-f signal at its own particular carrier frequency (which is a high frequency) by means of circuits which must be adjusted to that frequency, the high carrier frequency is changed to a much lower fixed frequency, so it can be amplified and the signals of unwanted stations eliminated much more efficiently. The fixed frequency at which the signals are amplified is called the intermediate frequency or i-f. The main difference between the tuned r-f system and the superheterodyne is that in the former the receiver is tuned to the frequency of the signal and the signal is amplified at that frequency, while in the latter the signal is tuned in and then changed in frequency to a lower value to which the intermediate amplifier is tuned and then the signal is amplified at the i-f frequency. A diagram showing the essential components of a superheterodyne is shown in Fig. 32. A voltage from many stations is induced in the antenna circuit. The signal of the wanted station is tuned by an r-f amplifier

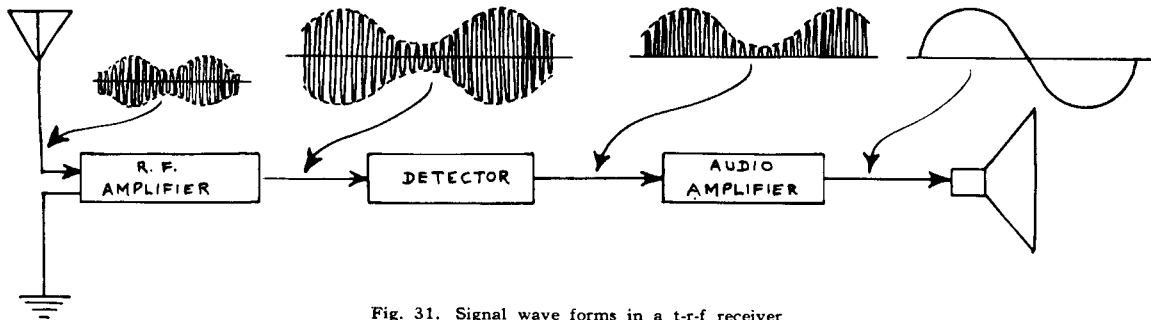


Fig. 31. Signal wave forms in a t-r-f receiver.

tem in that it is difficult to design an r-f amplifier which will give a gain of more than 40 per stage at the broadcast frequencies. This necessitates the use of many stages if high sensitivity is to be obtained. Also, since the primary of each r-f transformer induces a higher voltage into the secondary at the higher frequencies than at the lower ones, due to

or oftentimes directly by the converter tuning circuit where it is mixed in the converter with a steady signal of a definite frequency generated by the local oscillator tube. This local oscillator is tuned as the r-f signal of the station is tuned so that the oscillator operates at a frequency differing from the signal frequency by the amount equal to the fixed fre-

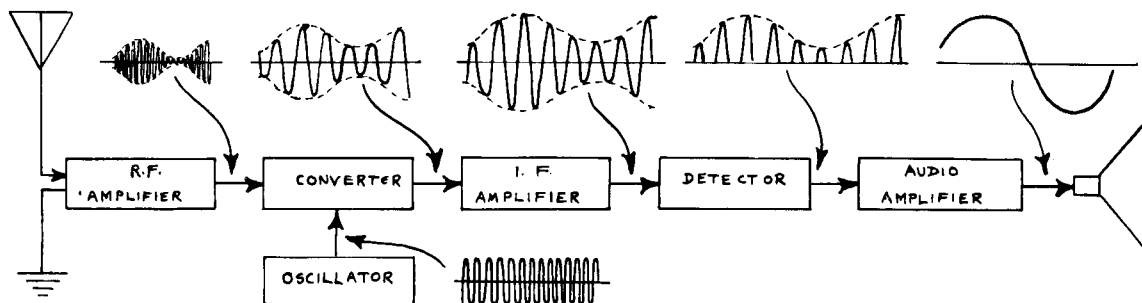


Fig. 32. Signal wave forms in a superheterodyne receiver.

the more rapidly varying magnetic field, the r-f amplification is not uniform over the entire broadcast band. Since all tuning circuits of the r-f receiver must be able to tune to all frequencies in the range that the receiver is to cover, these circuits

quency of the intermediate amplifier. After passing through the converter the local oscillator and signal frequency produce a resultant beat frequency voltage having the same frequency as that to which the intermediate amplifier is tuned and the same modu-

lation characteristic as that of the original signal frequency. This single frequency modulated voltage is amplified by the i-f amplifier then detected and changed to audio frequency at the detector, is further amplified by an audio amplifier, the resulting voltage of which is converted by the speaker into sound.

ADVANTAGES OF SUPERHETERODYNE

A superheterodyne has a number of advantages over the tuned r-f receiver by changing the frequency of the incoming signal to a resultant lower and fixed i-f frequency. These advantages include:

1. Higher gain per stage due to the lower frequency of the i-f.

2. The fixed tuned circuits of i-f amplifier result in higher efficiency.

3. More nearly constant sensitivity and selectivity over the entire tuning band.

REVIEW QUESTIONS

1. What are side bands?
2. Explain in your own words briefly how a superheterodyne receiver functions.
3. What is the purpose of the detector?
4. What is the main difference between a tuned radio frequency (t-r-f) receiver and a superheterodyne?
5. What is selectivity?

RECTIFIER AND POWER SUPPLY

POWER SUPPLY UNIT

The rectifying action of the two-element or diode type tube finds an important application in supplying the receiver with d-c power from the a-c power line. A typical arrangement for this application includes a power transformer, a rectifier tube, a filter and voltage divider. These various components function to step-up the 110-volt a-c voltage to the higher plate voltages necessary for the proper operation of the various tubes. It must rectify the a-c to pulsating d-c, it must smooth this pulsating d-c to a smooth d-c voltage, and must provide several intermediate voltages for the different types of tubes.

THE HALF-WAVE RECTIFIER

The half-wave rectifier is the simplest means of obtaining a d-c voltage from an alternating current. However, due to the fact that the half wave rectifier requires more expensive filters in order to obtain a satisfactory smooth flow of d-c voltage, it is not used very extensively in modern receivers.

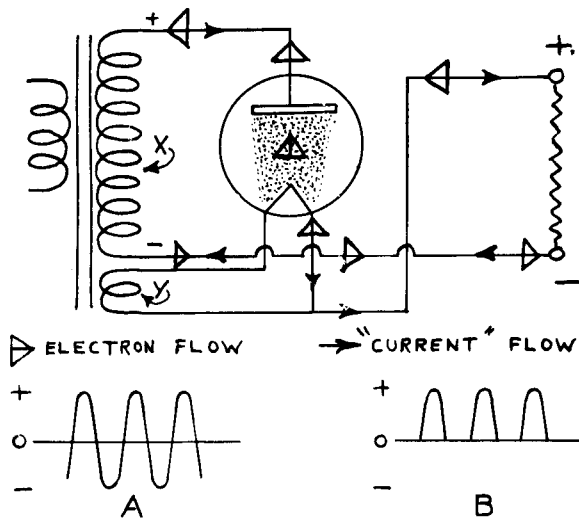


Fig. 33a

Fig. 33b

Fig. 33. Currents in a half-wave rectifier.

The connections of the tube to a transformer is shown in Fig. 33. The rectifier filament is heated by winding "y", while the high a-c voltage for the power supply voltage is provided by winding "X". Since the transformer operates on a-c, the polarity of the voltage reverses during each half cycle as shown in Fig. 33a. When the top terminal of the winding is positive and the bottom terminal is negative, as shown in the diagram, the plate of the rectifier being at a positive potential attracts electrons from the filament. The plate current then flows from plate to filament and out through the positive terminal of the power supply to the various tubes, then back to the negative terminal of power supply to the negative terminal of transformer, thus completing a closed circuit.

On the next half cycle the polarity of the transformer winding "X" changes, thus placing a negative voltage on the plate. This negative charge on the plate repels the electrons from the filament so

that no current flows through the rectifier. Therefore the current flows through the external circuit in one direction only; one spurt of current getting through the tube during the half of cycle when the plate is positive, as shown in Fig. 33b.

Based on the electron theory, which is the more accurate method of analysis, electrons will flow to the plate when it is positive with respect to the filament. Since electrons are NEGATIVE electricity, when the plate is positive, it must be deficient of electrons and they will be attracted to it. The electron flow can be traced by starting at the negative terminal of the transformer, which is also the negative terminal for the output of the rectifier. The electron current will flow from the negative terminal, through the load placed between the output terminals to the filament, and then through the tube to plate. Going through this cycle, electron pressure is used to produce work, which accounts for the voltage drops in the circuit.

The negative terminal might be considered as an abundant source of electrons of high pressure, and that in flowing through the circuit, the more pressure that is used up, the greater will be the voltage drops.

In Fig. 33b you will note that the current stops flowing entirely during half of each cycle. This makes it difficult for the filter to supply a smooth current, since the filter must actually store enough energy to keep a current flowing in the external circuit when no current flows through the rectifier. For this reason full-wave rectification is most commonly found.

FULL-WAVE RECTIFIER

In order to provide rectification on both halves of the a-c wave and therefore obtain a smoother pulsating d-c, the full-wave rectifier tube and circuit was devised. The connection to the transformer is shown in Fig. 34. Each plate is connected to a terminal of the high voltage winding "X". The center tap connects to the filter and load to provide a return path for the current.

On the positive half of the a-c cycle, the top terminal of the winding "X" is positive, thus making the right hand plate of the rectifier positive. The lower terminal of the winding and the left plate likewise are negative. A center tap of winding "X" is negative in respect to the upper terminal. In this condition the right hand plate passes current to the external circuit as shown by the arrows. It will be noted that only the upper half of the winding "X" is effective during this half cycle; therefore the effective voltage acting on the rectifier is one-half of the total voltage of winding "X".

On the negative half cycle, the polarity reverses, the left hand plate becoming positive and the right hand plate negative. The current then flows from the left hand plate to filament, while the right hand plate passes no current. The current, however, in the external circuit, is still in the same direction as on the positive half of the cycle, so we get a pulsating d-c current on both halves of the wave as shown in Fig. 34b. Since a full-wave rectifier

utilizes both halves of the a-c wave, the rectified wave is much smoother than that produced by a half-wave rectifier and is much easier to filter or smooth out.

The output of a rectifier tube is pulsating d-c,

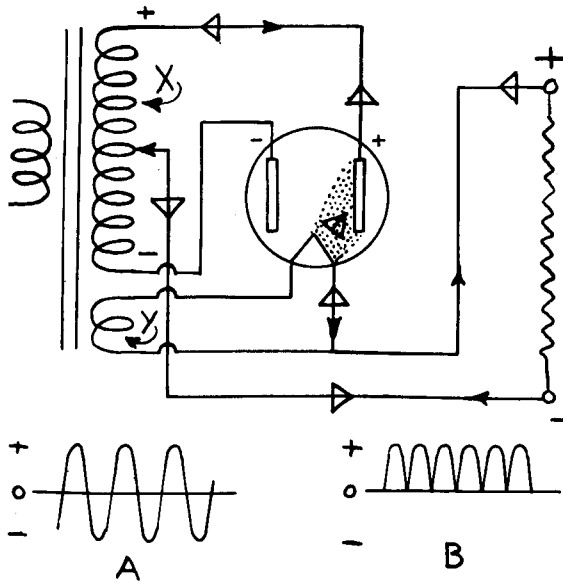


Fig. 34a Fig. 34b
Fig. 34. Currents in a full-wave rectifier.

which has to be smoothed out before it can be applied to vacuum tube circuits. A filter is used to smooth out these pulsations so that practically unvarying direct current is available. The filtering is accomplished by utilizing the stored energy in condensers and inductances which is built up while the pulsations are rising and restored to the circuit when the pulsations are falling, thereby filling in the valleys in the rectified output.

THE FILTER CIRCUIT

A typical filter for a radio receiver consists of two high capacity condensers and an iron core choke arranged as shown in Fig. 35. This choke is oftentimes the field of an electrodynamic speaker, thereby serving two purposes. The present trend, especially in smaller receivers, is to use a resistor in place of the choke. The choice between a resistor and choke depends chiefly upon the permissible d-c drop through the filter. In circuits where the current is small, resistors are practical; where the current is large, chokes are more suitable.

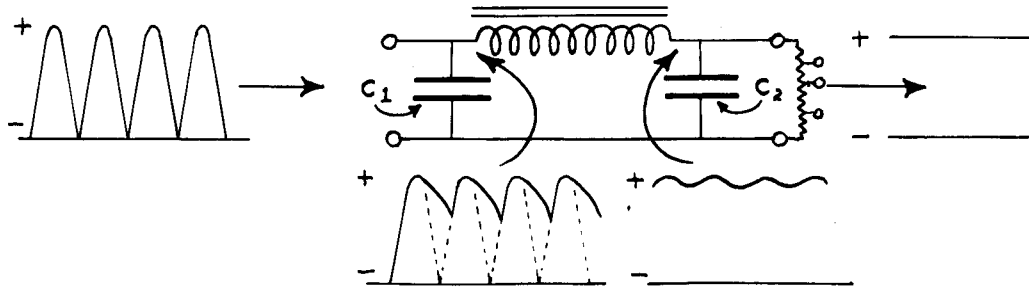


Fig. 35. Action of a filter.

The pulsating rectified voltage shown in the dotted line in Fig. 35 is applied across the first filter condenser "C₁". This condenser becomes charged on

the first positive pulse from the rectifier and when the rectified a-c wave decreases to zero, the charge on the condenser then supplies the external circuit, as shown in the heavy line. This is a fairly steady direct current; however, it has considerable ripple voltage. By passing it through a choke, which we found opposes any change in current in the circuit, and then applying it to another condenser, "C₂", we obtain a steady d-c voltage comparable to that supplied by a battery.

The first condenser, "C₁", then may be considered a voltage regulator in that it absorbs energy on the peaks of the rectified voltage, and this fills in the valleys between peaks. The choke irons out the fluctuation of current by opposing any change. The second condenser, "C₂", acts as a storage reservoir for the power supply. Thus if a loud low frequency note is suddenly reproduced, the plate current will suddenly increase in the tubes, therefore causing an IR drop in transformer, choke, rectifier tube, etc., which in turn would lower the applied plate voltage if it were not for the last condenser "C₂". This condenser being a reservoir for energy will supply the momentarily increased plate current drain without affecting the rest of the power supply unit.

Because of the high capacity required for adequate filtering, the electrolytic condenser is used entirely for the power supply unit.

The voltage divider (voltage dropping resistor or resistors) on the output of the filter lowers the voltages to fit the requirements of the various tubes.

THE VOLTAGE DOUBLER RECTIFIER

The voltage doubler is used in some of the transformerless receivers to supply d-c voltages, which

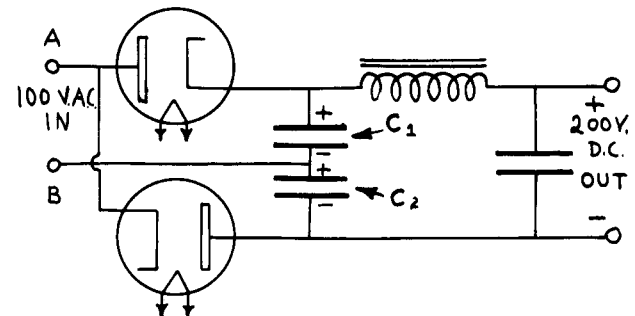


Fig. 36. Voltage doubler rectifier circuit.

are usually twice as high as the a-c input voltage. Such a circuit is shown in Fig. 36.

On the positive half-cycle of the a-c cycle, the upper end of the a-c line is positive with respect to the lower side so the upper rectifier tube passes cur-

rent and feeds a positive charge to the condenser "C₁" which stores this charge. On the next half-cycle, the upper side of the line is negative with respect to the lower side, and the lower rectifier passes current, so a negative voltage builds up across the lower condenser. It can be seen from the diagram then that the two voltages will add up to give a voltage equal to twice the voltage stored on each condenser.

BASIC A-C D-C POWER SUPPLY HALF-WAVE RECTIFIER

In the a-c, d-c power supply, the filaments of all the tubes are usually placed in series across the a-c line voltage. This means that the rated filament voltages of the tubes, added together, total to the line voltage. If they do not, the difference is made up by some type of ballast or dropping resistor. Since they are in series, the amount of current flowing is the same for each part of the series circuit, and similar type tubes cannot be used for replacements if the filament current ratings are different from the original.

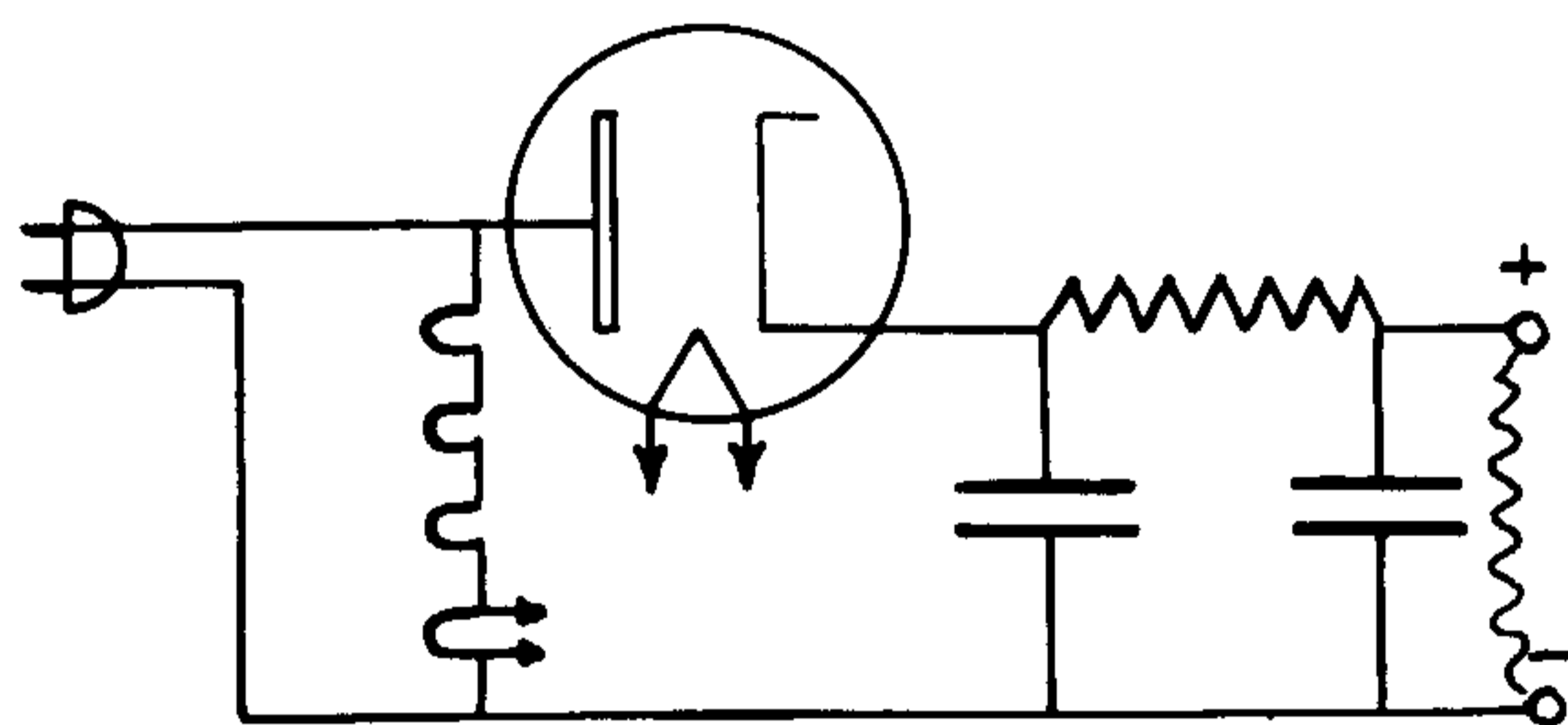


Fig. 37. A-C D-C rectifier circuit.

Various schemes are used to insert pilot lights. The most common is to use a 6-volt light across one-half of the rectifier filament with a suitable resistor to adjust voltage and current correctly.

The circuit is basically a simple half wave rectifier.

COPPER OXIDE RECTIFIER

With the use of the copper oxide rectifier in a recent receiver of the portable type, their popularity will possibly be revived for radio purposes, as in the days when they supplied rectified a-c for the fields of loudspeakers.

Any device which offers a high resistance to the flow of current through it in one direction, and a comparatively low resistance to the flow of current through it in the opposite direction, makes a good rectifier for an alternating voltage. This is the case of the dry contact rectifiers, such as the copper oxide type. The copper oxide rectifier is made in the form of a copper disc, coated on one side by a layer of

copper oxide. The copper oxide is plated with nickel to allow good external circuit contact. The juncture of the oxide and copper offers a low resistance to the flow of current from the oxide to the copper but a high resistance to the flow of current in the reverse direction. The detailed operation of this device is complex, but in general it involves the formation of thin films at the junction of the oxide and copper in which the molecules are so polarized that the transfer of electrons in one direction requires much less work than a similar transfer in the opposite direction.

Copper oxide rectifiers possess a definite breakdown voltage and breakdown temperature. If either critical value be exceeded, the rectifier will pass current freely in both directions. After the unit is cooled or the high voltage removed, it will immediately function again as though it had not been overloaded.

The copper oxide rectifier can be connected in either the half-wave rectifier or full-wave rectifier circuit.

The test for proper single disc operation is to impress a 1/2-volt d-c across the disc in the conducting direction; then the current should read 0.5 ampere or more. By reversing the battery polarity, a current of no more than 2 1/2 milliamperes should flow when 2 volts is applied to the disc in the non-conducting direction.

REVIEW QUESTIONS

1. Explain the difference between a half-wave rectifier and a full-wave rectifier (operation only).
2. What does the filter accomplish in a power supply?
3. How does the filter function, when using condensers and inductance?
4. Is the output of a rectifier tube
 - a. a-c?
 - b. Pure d-c?
 - c. Pulsating d-c?
5. If the input to a full-wave rectifier tube is 60 cycle a-c, would the rectifier voltage have any variations with no filter at
 - a. 60 cycles?
 - b. 30 cycles?
 - c. 120 cycles?
 Explain.
6. Upon what main principle does a voltage doubler rectifier operate?
7. If a five-tube a-c d-c receiver uses 6-volt .25-ampere filament tubes, how much resistance would be needed to connect the tubes in series across the 110-volt line?
8. What will be the power dissipated in the resistor?

ANTENNA AND R-F

LOOP ANTENNAS

Modern receivers are so sensitive that a loop antenna is used in most receivers for the reception of local and semi-local stations. A loop antenna is in reality an r-f coil without a primary coil and is tuned by a variable condenser to give a high voltage to the grid and cathode of the first tube by resonating to the desired signal. By making the loop large and of heavy wire to reduce resistance, the Q of the coil or loop is made high, giving a large transfer of energy or signal pick up. The directional effects makes the loop especially desirable for preventing local noise sources from interfering with the station signal.

TRIODE TUNED RADIO FREQUENCY AMPLIFICATION

In Fig. 38 is shown a single stage of tuned radio frequency amplification which could precede the detector in a simple t-r-f receiver or the converter tube in a superheterodyne. R-f transformers are used to couple both the grid and the plate circuits of the r-f amplifier tube to the circuits. For example: In the simple t-r-f receiver this means of connecting the primary of the first transformer into the antenna circuit and the secondary in the grid circuit of the r-f amplifier tube as shown. The plate circuit of of

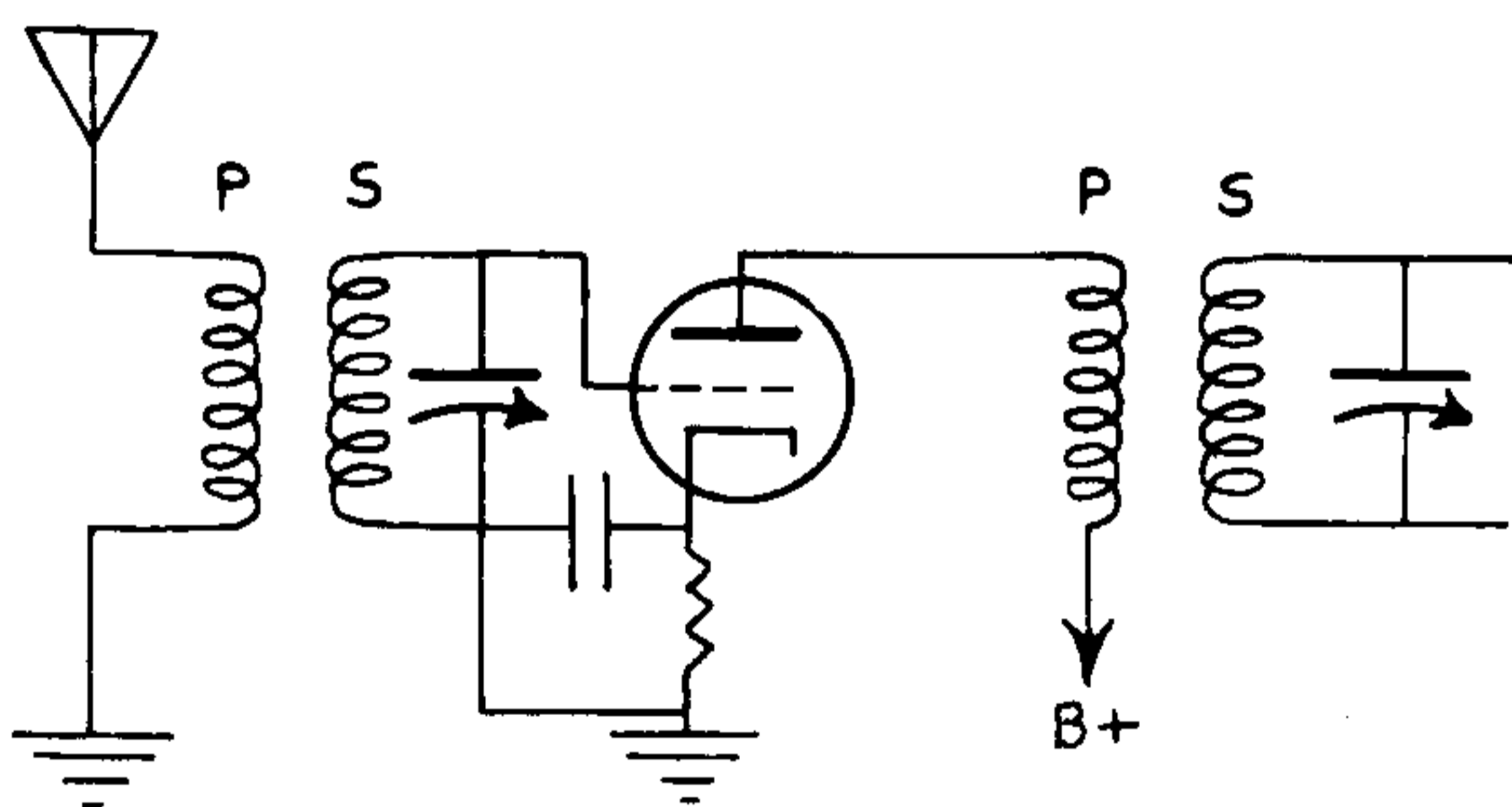


Fig. 38. Tuned radio frequency amplifier circuit.

this tube is now coupled to the detector or succeeding tube by a similar transformer. The secondary of each transformer is tuned by means of the variable tuning condenser as shown to form a resonant circuit as described earlier.

The weak r-f voltages induced in the antenna by the various broadcasting stations cause currents of corresponding frequencies to flow in the primary between the antenna and ground. The currents flowing through the primary coil of the first transformer produce magnetic fields which link with the secondary coil and induce potentials of corresponding frequencies in it. This secondary coil and its associated tuning condenser form a resonant circuit, the resonant frequency of which is determined by the inductance of the coil and the capacity setting of the condenser. The impedance or opposition to the flow of current of this resonant frequency is very small while the opposition to the flow of currents of all other frequencies is high. Therefore, the induced voltage across the secondary coil at this resonant frequency is the voltage applied between grid and

cathode of the tube. This voltage amplified by the r-f tube is produced as a much larger r-f voltage in the second transformer in the plate circuit of the r-f tube. This amplified voltage is now detected or amplified further by more r-f stages depending on the application.

When coupling the plate circuit of a tube to the grid circuit of the following tube by an r-f transformer, in reality this transformer changes the pulsating plate current of the r-f tube into an alternating r-f voltage for the grid circuit of the following tube. Obviously the higher this input voltage to the grid circuit of the second tube can be made, for a given value of pulsating current in the plate of the first tube, the more efficient will be the coupling and the louder the signal. Therefore the transformer is usually constructed so that there is a greater number of secondary turns than primary turns in order to give a step up in voltage. This is not always true, however, as greater amplification will be obtained from an r-f amplifier tube when the impedance of the primary forms the plate circuit load for the tube.

R-f amplification is characterized by the fact that higher gain is obtainable at the high frequency end of the broadcast band than at the low frequency end, due to the more rapidly varying magnetic field. Also r-f amplification is limited to a gain of about 40 per stage in the broadcast band.

MULTIPLE TUNED R-F AMPLIFIER

A single r-f amplifier stage before a detector is hardly satisfactory due to insufficient selectivity or ability to separate stations and insufficient amplification of the received signal. Therefore a number of stages with their coupling transformers may be added; the number being determined by the amplification desired and the selectivity. The tuning of a multiple stage r-f amplifier is effected by means of ganging the condensers together so as to tune them with a single control. The variations in stray capacities of the circuits and the difference in coils and condensers which would seriously affect the high frequency end of the band is compensated for by adding a small trimmer condenser across each individual condenser and then aligning the receiver at a high frequency point; as for example 1500 kc on the broadcast band.

ADVANTAGE OF PENTODE OVER TRIODE IN R-F AMPLIFIERS

The triode tube is not very well adapted for use in r-f amplifiers because of its very low plate resistance as compared to other tubes which are available. A tube with a low plate resistance does not produce very much gain per stage.

Another factor is the fact that small interelectrode capacitances between the tube elements are not entirely negligible, especially at the high radio frequencies. The interelectrode capacities are especially bothersome in triodes. When the plate load is inductive, part of the output is fed back into the grid input circuit through the grid-plate capacity of the tube. It is reamplified by the tube and appears again in the output circuit. This regeneration or buildup of energy can become so great as to get entirely out

of hand, causing oscillation. The tube then no longer acts as an amplifier but as a generator of radio frequencies.

In the triode r-f amplifier, oscillation may be prevented by introducing resistance into the grid circuit such as 200 ohms in series with the grid of the tube, or the more general and satisfactory means is by neutralization. A neutralizing circuit is shown in Fig. 39a. Here a small capacitor C_N introduces a

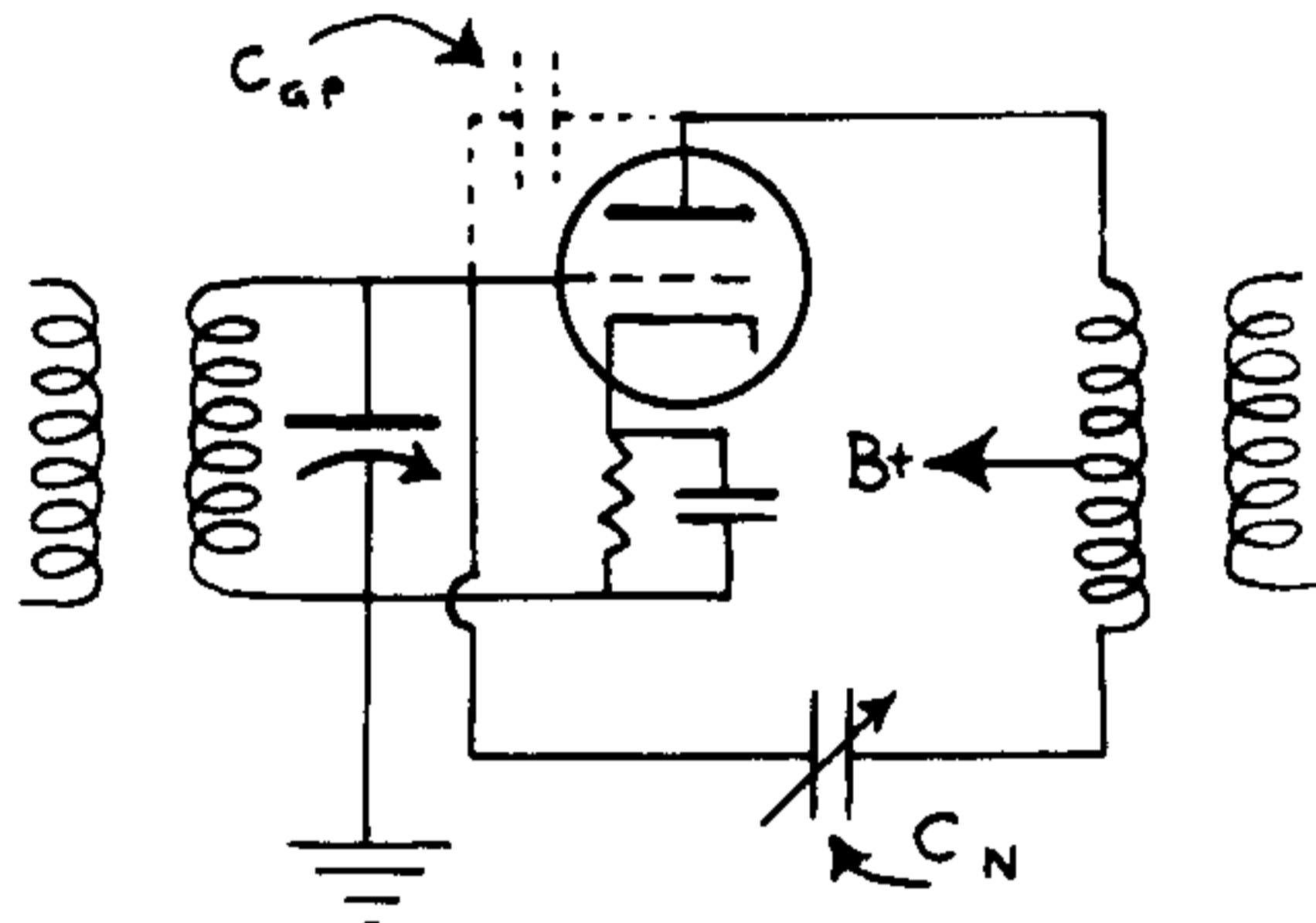


Fig. 39a. Circuit for neutralizing grid-to-plate capacity of a triode tube.

voltage from the output circuit which is of opposite phase and value to that produced by the plate-grid capacity C_{gp} . In this way the voltage induced in the grid circuit by the feedback is largely canceled and reduced so that regeneration is prevented.

However, in the screen grid tetrode, or pentode, we have a means of obtaining high amplification without the necessity of neutralizing. In the section on pentodes, we learned that the screen grid was placed in the tube to shield the plate from the grid electrostatically (capacity coupling). This screen grid is held at a definite positive potential in order that the electrons may reach the plate; however, it must also be maintained at ground potential in respect to the r-f signal so as to effectively shield the plate from the grid. This is accomplished by connecting a capacitor C_1 as shown in Fig. 39b between the screen and cathode or ground; its value is chosen large enough so that it will act as a short circuit to ground with respect to any r-f signal.

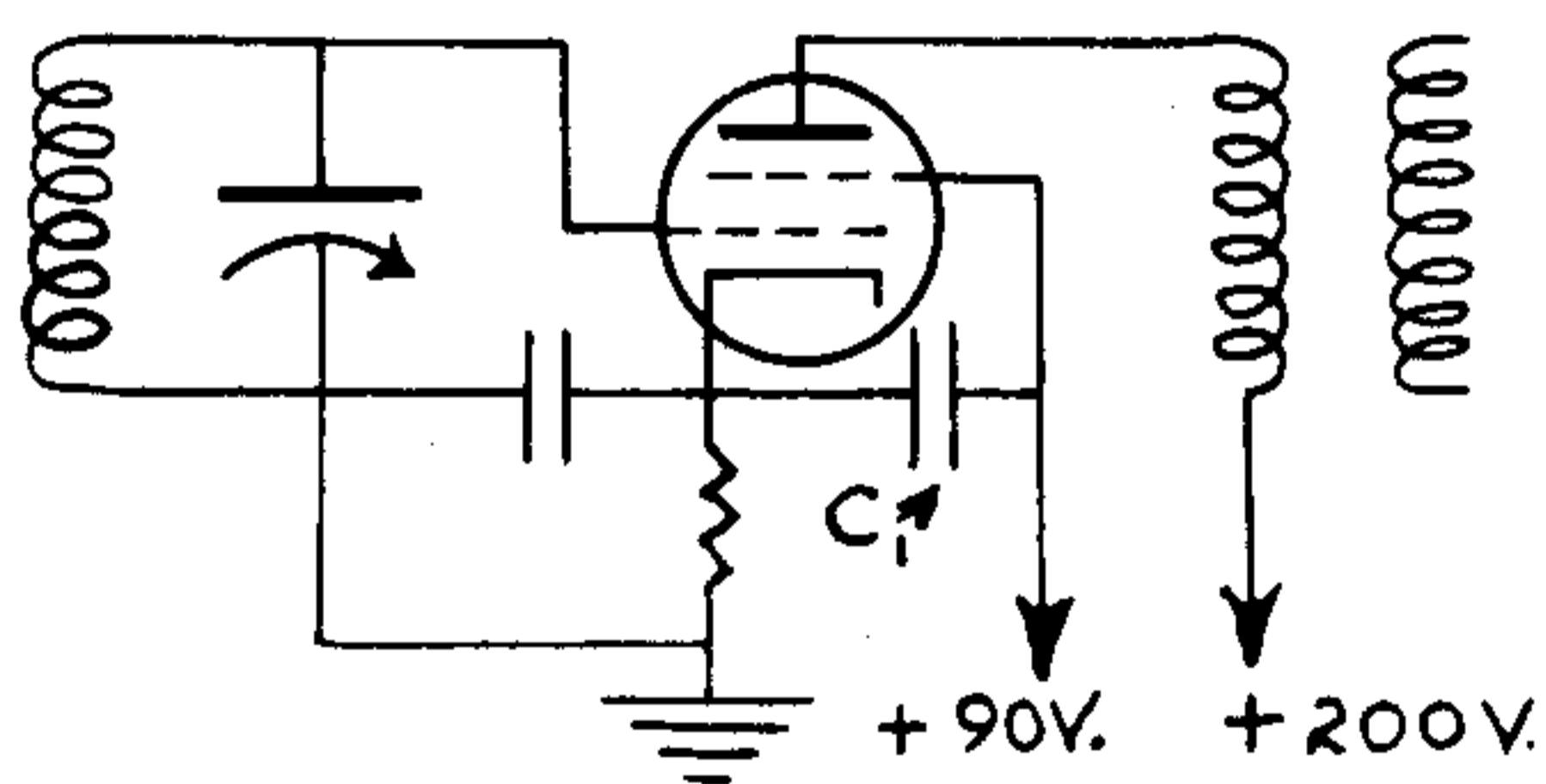


Fig. 39b. Circuit using a screen grid tube.

Since the screen is maintained at ground potential, as far as the signal frequencies are concerned, its potential cannot change. It simulates therefore a perfect capacity shield between the grid and plate within the tube. To completely shield the plate of

the screen grid tube, it is necessary to provide a shield external to the plate itself. This is usually an aluminum tube shield over the entire glass tube which is grounded to the chassis or in the metal tube, the outside shell acts as the shield.

In addition to the fact that screen grid tubes do not require neutralizing, they afford much greater amplification than the triode due to their high plate resistances.

R-F RESISTANCE COUPLED AMPLIFIERS

Resistance coupled r-f amplifiers are used quite generally in present receiver design, especially where push button tuning is incorporated. Since it is rather hard to move a three-gang condenser where mechanical push button tuning is used, or to necessitate the set-up of three trimmer adjustments for each station where the electrical push button tuning is used, the resistance coupled r-f amplifier solves this problem of complication in automatic tuning circuits.

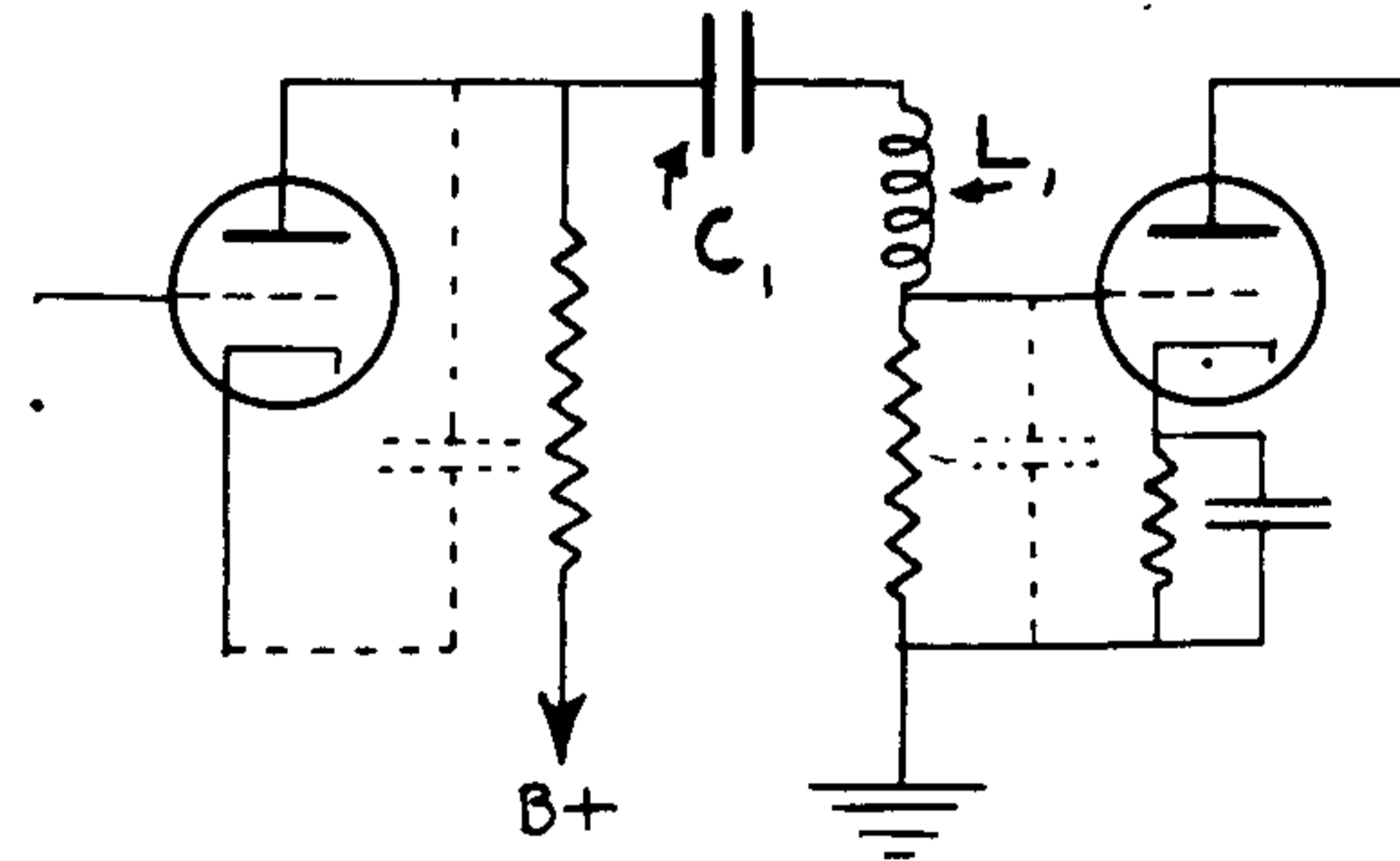


Fig. 40. Resistance coupled radio frequency amplifier circuit.

This type r-f amplifier also passes a very wide band of frequencies, making it especially adaptable to FM and television. Since the input capacity of the grid circuit of the tube following the resistance coupling offers low reactance to high r-f frequencies, a small inductance, " L_1 ", is added in series with the coupling condenser " C_1 " to isolate the grid capacity from the plate of the preceding tube. This maintains the tubes' amplifying efficiency at high frequencies.

REVIEW QUESTIONS

1. Is there any advantage of "tuning" a signal before it reaches the first tube in the receiver? Explain briefly.
2. What do you interpret as the meaning of "gain" of an r-f amplifier?
3. Why is a pentode tube usually better as an r-f amplifier than a triode?
4. If voltage amplified by a tube is reinserted into the grid of that tube, what could occur?
5. Would polarity of voltages have any bearing on the above question?

OSCILLATOR AND CONVERTER

THE OSCILLATOR

Under the proper conditions a vacuum tube will act as an oscillator, generating a continuously alternating voltage from the audio frequencies to ultra high r-f. In the radio receiver the oscillator is only used in superheterodynes, where it supplies the necessary fixed frequency for the beat frequency for which the intermediate amplifier is designed, with every signal which it may be desired to receive. In order to produce oscillation, the following conditions in the vacuum tube circuit must be fulfilled: (1) The tube must be an amplifier, (2) The voltage induced in the grid coil by the plate circuit must be of the proper polarity, and (3) The energy fed back to the grid circuit from the plate must more than make up for the power loss in the grid circuit.

The losses in the grid circuit are due to the resistance of the coil, the condenser, and the grid cathode resistance of the tube. Even though the tube is biased negatively, it may become positive during certain parts of the cycle, and during these times it draws current and dissipates power which must be supplied by the plate. Hence the voltage in the plate must be great enough to supply this power. This extra plate circuit signal power will only be available if the tube is an amplifier.

Many types of oscillator circuits can be used in the superheterodyne circuit. However, there are two types which we will study because of their simplicity and their common usage in present day receivers. The circuit shown in Fig. 41a is the best known oscillator circuit and is the tickler feedback method. The circuit shown in Fig. 41b is the parallel or shunt Hartley oscillator circuit.

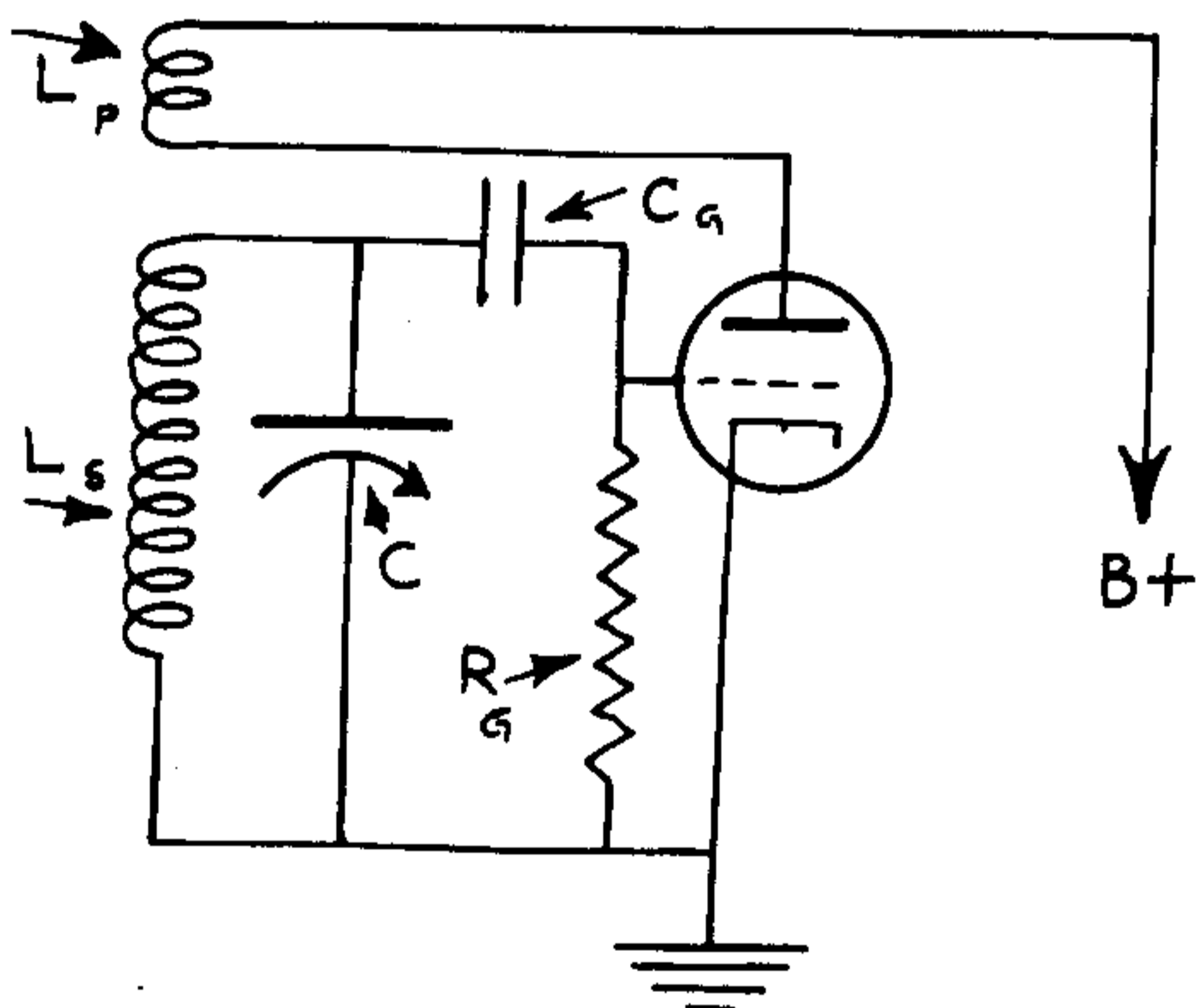


Fig. 41a. Tickler feedback oscillator circuit.

In the tickler feedback method, an oscillator coil having two separate windings is used. The windings must be connected so that the grid end of one winding will be of opposite polarity with respect to the plate end of the other. This is done to accomplish a 180° phase shift. With this arrangement the plate of the tube is connected to B+ voltage through the plate tickler coil "Lp". When voltage is applied to the plate suddenly, plate coil "Lp" induces a voltage in the grid coil "Ls" by transformer action. A voltage appearing across "Ls" is applied to the grid of the tube. The plate current tends to vary

according to the variation in grid potential over the oscillation cycle. Although it may be considerably distorted it has a component of plate current of the frequency of the grid voltage. This component of plate current flows through the plate tickler coil "Lp", induces a voltage into the tuned grid coil to produce the grid voltage first assumed and thereby sustain oscillation. The resonant grid circuit determines the frequency of oscillation. It is apparent that the degree as well as the direction of coupling of the two coils "Ls" and "Lp" is important. If the coupling is too small, so that the induced voltages from the plate tickler into the grid circuit is not enough to overcome the grid losses, the oscillations will not sustain themselves. If too much coupling is used, the oscillator will become unstable or may refuse to oscillate. A grid leak, "Rg", is used to produce self bias on the oscillator. During the first positive half cycle of the induced voltage in the grid, the grid is positive and current flows from grid to cathode and up through resistor "Rg" to the grid.

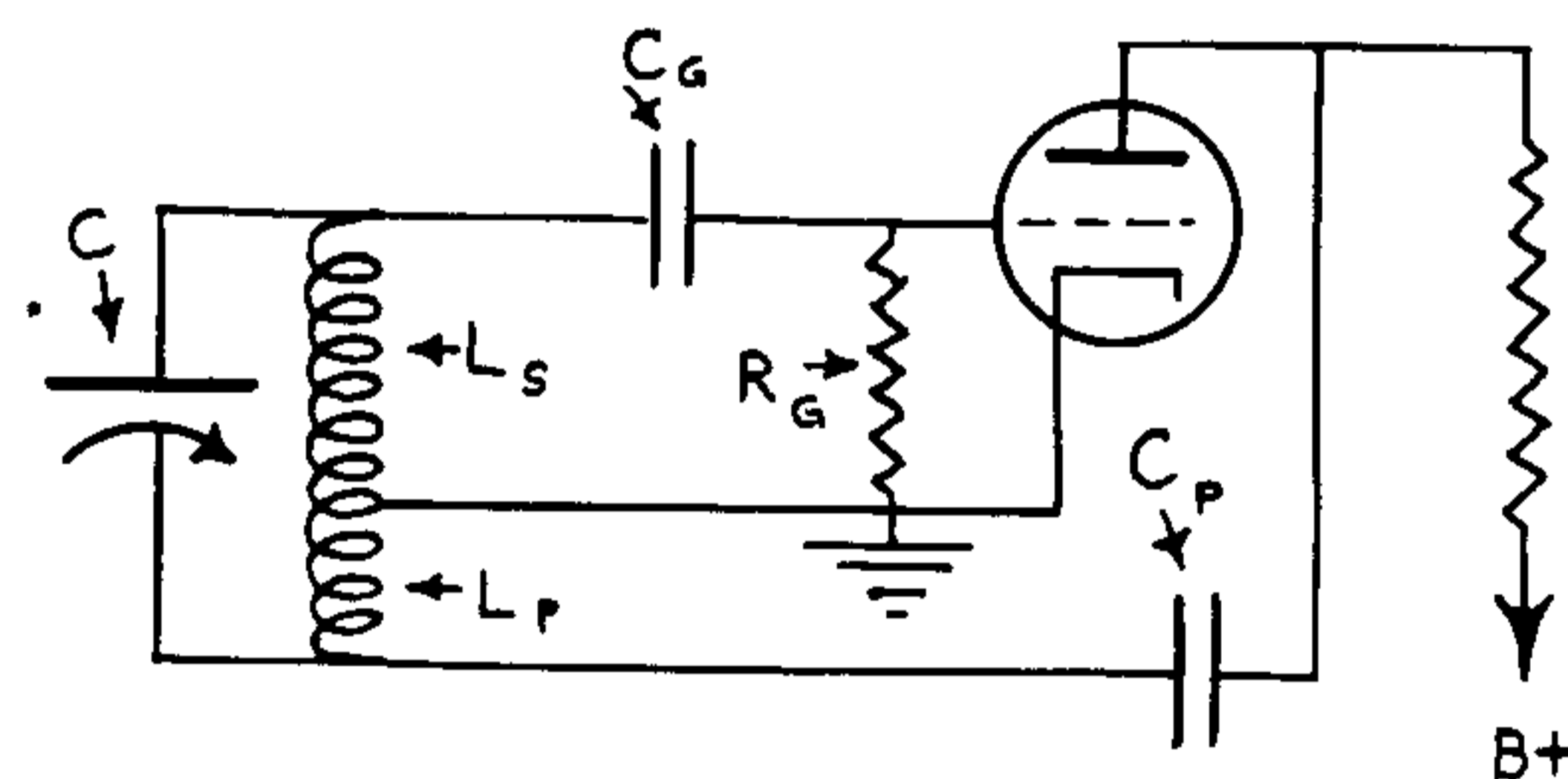


Fig. 41b. Oscillator circuit using single inductance.

This causes a voltage drop across the grid resistance, the "grid" end being negative with respect to cathode. This negative bias prevents the tube from drawing too much plate current and thereby overloading and decreasing its life. The grid condenser "Cg" is used solely to block this d-c bias voltage from being shorted by the coil "Ls".

The operation of the shunt feed oscillator shown in Fig. 41b is very similar to the two winding transformer or tickler feedback method, except that it uses an autotransformer. In this case the plate is connected to the plate end of the winding through the B+ blocking condenser "Cp". Since the opposite ends of the autotransformer are connected to grid and plate respectively, they are of opposite polarity and the condition for 180° phase shift has been met. The point at which the cathode tap is connected to the autotransformer determines the degree of feedback between the winding "Ls" and "Lp". The complete coil is in the tuned circuit and forms the resonant circuit with the tuning condenser "C".

The oscillator triode is often incorporated in a pentagrid converter tube in the modern superheterodyne, thereby combining two tubes into one.

FREQUENCY CONVERSION IN SUPERHETERODYNE

The superheterodyne type of circuit depends for its operation on what are termed "beat" frequencies.

When two different frequencies are combined in a tube, the resultant output of the tube will have the sum and difference frequencies.

If a radio signal is applied to the grid of the mixer or converter tube, and an oscillator is coupled to the circuit carrying the radio signal, with the oscillator tuned to a frequency either slightly higher or lower than the radio signal, these sum and difference frequencies will be produced. By placing a transformer in the plate of this mixer tube which is tuned to either the sum or difference, the new beat frequency will be tuned by this circuit and passed on to the next stage (i-f amplifier). Normally the difference frequency is used in the superheterodyne because it is easier to amplify the lower frequency with a high resultant gain per stage.

By varying the resonant frequency of both the input signal of the antenna and that of the local oscillator circuit in step, stations on different frequencies can be picked up from the antenna and beat against the local oscillator to produce the same difference or intermediate frequency over the complete tuning range of the receiver. This allows the intermediate amplifier to be tuned to a fixed frequency and all signals in the tuning range are converted to this intermediate frequency by the local oscillator.

IMAGE FREQUENCY

One of the serious drawbacks to the superheterodyne type of receiver is the image frequency effect. Since the frequency of the beat produced is equal to the difference between the frequency of the carrier wave of the incoming signal and the oscillator, thus for any one oscillator frequency setting there is a frequency above this and one below this where the difference between them and the oscillator frequency is the same i-f frequency. For example, if the i-f amplifier was designed for 455 kc and the oscillator was tuned to 1100 kc, in which case both a 645 kc station signal and a 1555 kc station signal could beat with the local oscillator to produce a resultant beat of 455 kc and be amplified. These two stations being received at once would cause interference. To overcome this the converter tube can be preceded by an r-f amplifier or pre-selector circuit so as to cut out the undesired station. This condition becomes exceedingly troublesome when operating at extremely high frequencies and when using a relatively low i-f frequency.

OSCILLATOR FREQUENCY

We have seen that the i-f can be produced either by operating the oscillator higher or lower by 455 kc than the signal frequency. Since the maximum frequency range which we can cover in one band without changing a coil or condenser is a little over 3 to 1 change in frequency, if we made the oscillator so it runs at a lower frequency than the signal to cover the broadcast band the oscillator would have to vary from 95 kc to 1145 kc when the i-f is 455. Since this is a change of almost 12 to 1, we could not design the oscillator to cover it without switching coils. If we make it higher the oscil-

lator would then have to cover from 1005 kc to 2055 kc for the 550 to 1600 kc broadcast band. This would be practical as it is only a 2 to 1 frequency change. This necessitates that the oscillator be run at a frequency which is equal to the i-f higher than the desired station signal.

TRACKING

In order to make the oscillator always maintain the same difference frequency from the r-f signal at all points, it is necessary to control the frequency range of the oscillator circuit in order to make it track with the r-f tuning circuit.

Two methods are employed. In some single band sets the plates of the variable condenser section tuning the oscillator are made smaller. This is called the cut-plate method of tracking. The other and more common method is the use of an oscillator variable condenser section similar to that tuning the r-f signal and then connect a series fixed or semi-fixed condenser (known as padder) in series with the oscillator section of the condenser. The series condenser restricts the overall capacity of oscillator section of condenser, and thus restricts the frequency coverage.

THE FREQUENCY CONVERTER

There are three common methods of converting the incoming frequency to the intermediate frequency. These methods are alike in that they employ a converter (frequency mixer) tube in which plate current is varied at a combination of signal and oscillator frequencies. These variations in plate current produce across the first i-f transformer primary the voltage of the desired intermediate frequency. The three methods differ in types of tubes used and in method of supplying signal and oscillator voltages to the mixer tube.

A method used widely in the early days of the superheterodyne was to use a triode, tetrode or pentode as the mixer tube and insert the oscillator and r-f signal voltage into the same control grid. The oscillator voltage was usually impressed on the signal grid through a condenser or by means of transformer action into the r-f coil.

The second method employs a pentagrid-converter tube such as the 6A8. In this tube the oscillator and frequency mixer are combined into one tube with coupling between the oscillator and mixer circuits obtained by means of the electron stream within the tube. The cathode, oscillator grid and oscillator plate are connected to an external circuit to act as a triode oscillator. These three elements can be considered as a composite grid which supplies the rest of the tube with an electron stream that varies at the oscillator frequency. Thus the variations of the plate current are due to the combination of the oscillator and signal frequencies. The signal grid, screen, and plate act as a regular pentode for the signal frequencies.

The third method makes use of two separate tubes, one used as an oscillator, the other the con-

verter. The converter tube can have the oscillator voltage applied to one element (cathode, suppressor, grid, plate), and the signal to the control grid. By so doing, greater stability and amplification are possible when special requirements demand, such as in television, FM, etc.

The i-f or other beat frequencies could not be obtained if the converter tube operated on a linear characteristic, since the output would be a replica of the input wave forms.

REVIEW QUESTIONS

1. Is there any function of the grid circuit of an oscillator resembling a rectifier circuit?
2. How is the i-f voltage obtained in a superheterodyne receiver?
3. What is an image frequency?
4. Explain briefly the meaning of "tracking".
5. Can you see any reason why a frequency converter is also known as a first detector? Why?

I-F AMPLIFIER

THE INTERMEDIATE FREQUENCY (I-F) AMPLIFIER

The intermediate frequency amplifier consists of one or more stages of radio frequency (r-f) amplification tuned to a fixed frequency. This frequency is 455 kc in modern broadcast receivers, although intermediate frequencies as low as 175 kc are general, especially in automobile receivers. As the intermediate frequency is much lower than the input or desired signal frequency, and since tuned input

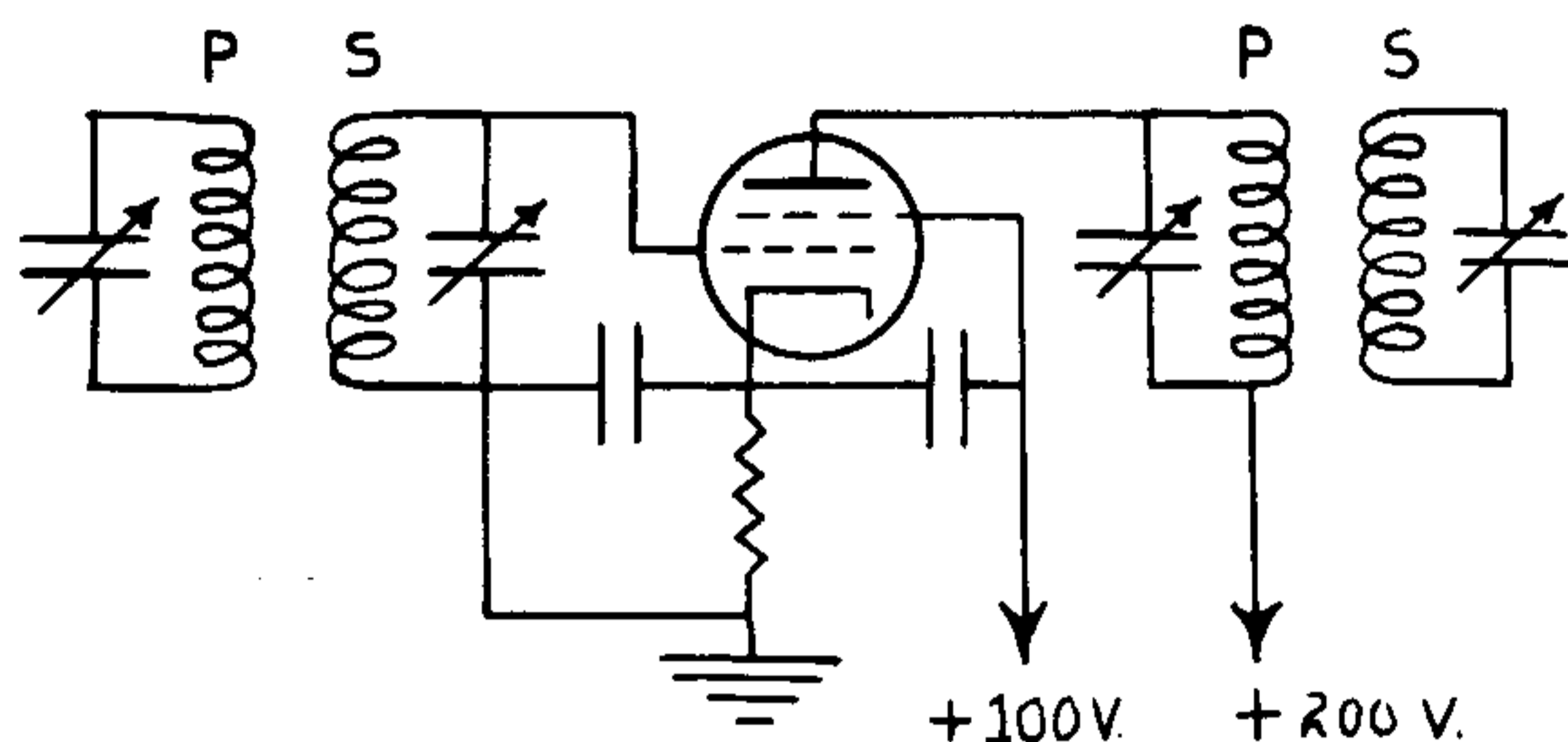


Fig. 42. Intermediate frequency amplifier circuit.

and output circuits are used in each i-f stage, it is comparatively easy to design an i-f amplifier to produce a high gain per stage with good selectivity and constant over-all gain.

LOSS OF GAIN DUE TO CATHODE DEGENERATION

The omission or open-circuit of the by-pass condenser C across the automatic bias resistor R can reduce the sensitivity as in Fig. 43 of the receiver a great deal.

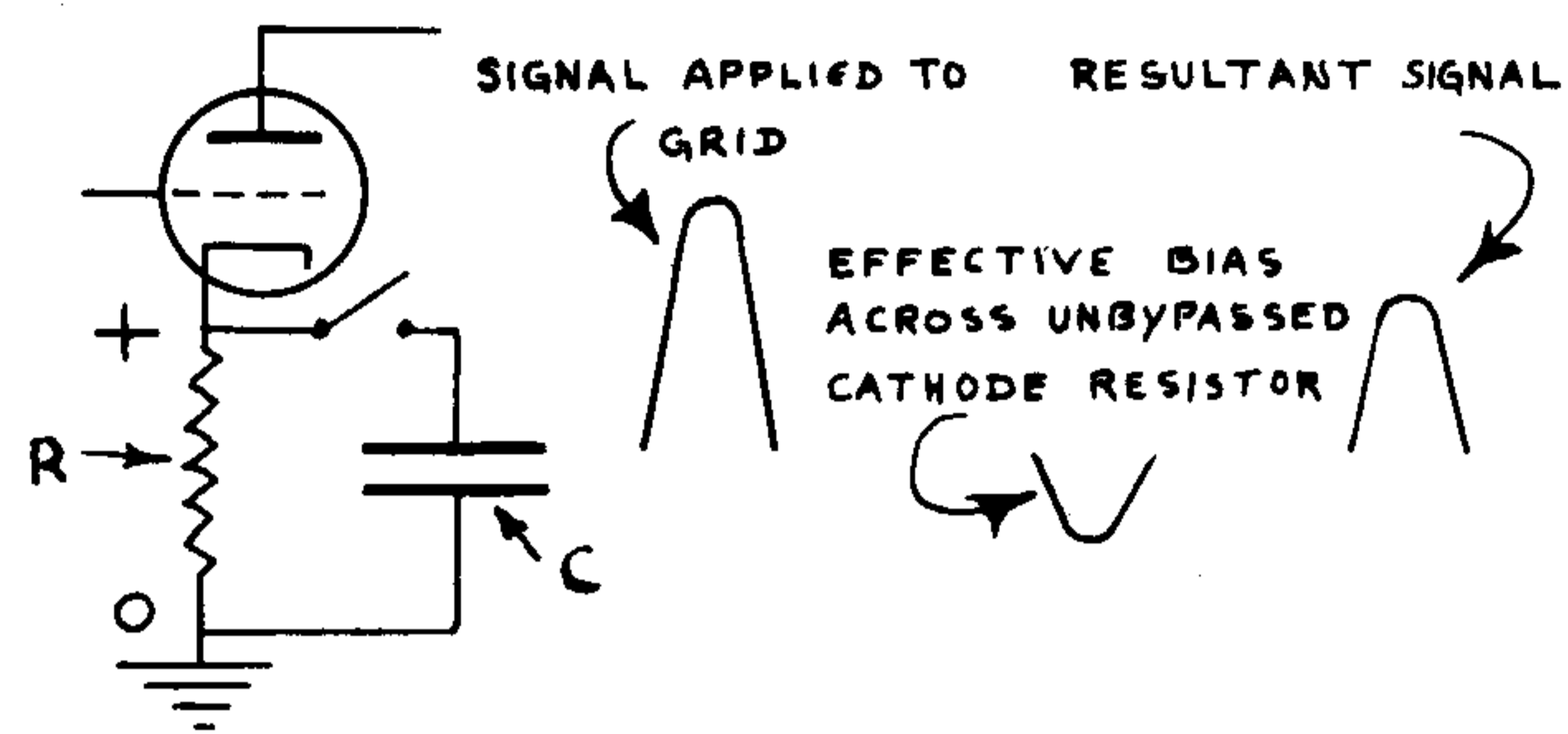


Fig. 43. Effect of by-pass condenser across cathode bias resistor.

It is the purpose of by-pass condenser C to maintain sufficient electrical charge so that the voltage across R remain constant during the individual alternations of the r-f signal. When C is open or left out of the circuit, the result is called degeneration.

DETECTOR AND A.V.C.

DETECTION

We found previously that when speech or music is transmitted from a radio station, the station sends out an r-f voltage wave whose amplitude varies in accordance with the audio frequency or intelligence which is impressed on it. This r-f or carrier wave is then said to be modulated.

In the receiver, it is necessary to make the r-f station carrier bearing the modulation intelligible. This process is called demodulation or detection. Demodulator is a better term than detector for this stage in the receiver because the modulation envelope is in effect detached from the carrier wave and made audible.

There are three different types of detector circuits in general use; they are: the diode detector, the grid bias detector, and the grid leak detector. They all behave similarly in that they eliminate either partially or completely alternate half-cycles of the r-f wave. With the alternate half-cycles eliminated, the audio variation of the top half of the r-f carrier can be used to actuate headphones or be amplified to drive a loudspeaker. Only the diode detector will be explained here.

THE DIODE DETECTOR

The diode detector is the most popular type of detector circuit found in the modern receiver because it produces less distortion than by the other two methods and also provides an easy means of obtaining a-v-c voltage. In Fig. 44 is shown a simple diode circuit detector.

This circuit is very similar to the half-wave rectifier circuit as studied in the section on power supplies. Considered in this way, the diode is the half-wave rectifier tube, the r-f signal is the a-c input, the r-f by-pass condenser C is the filter condenser, and the resistor R is the load resistance. Because the output d-c voltage of a rectifier depends on the voltage of the a-c input, the d-c voltage across C varies with the amplitude of the r-f carrier and thus reproduces the audio signal. The bottom half of the wave (below A) is cut off in rectifying.

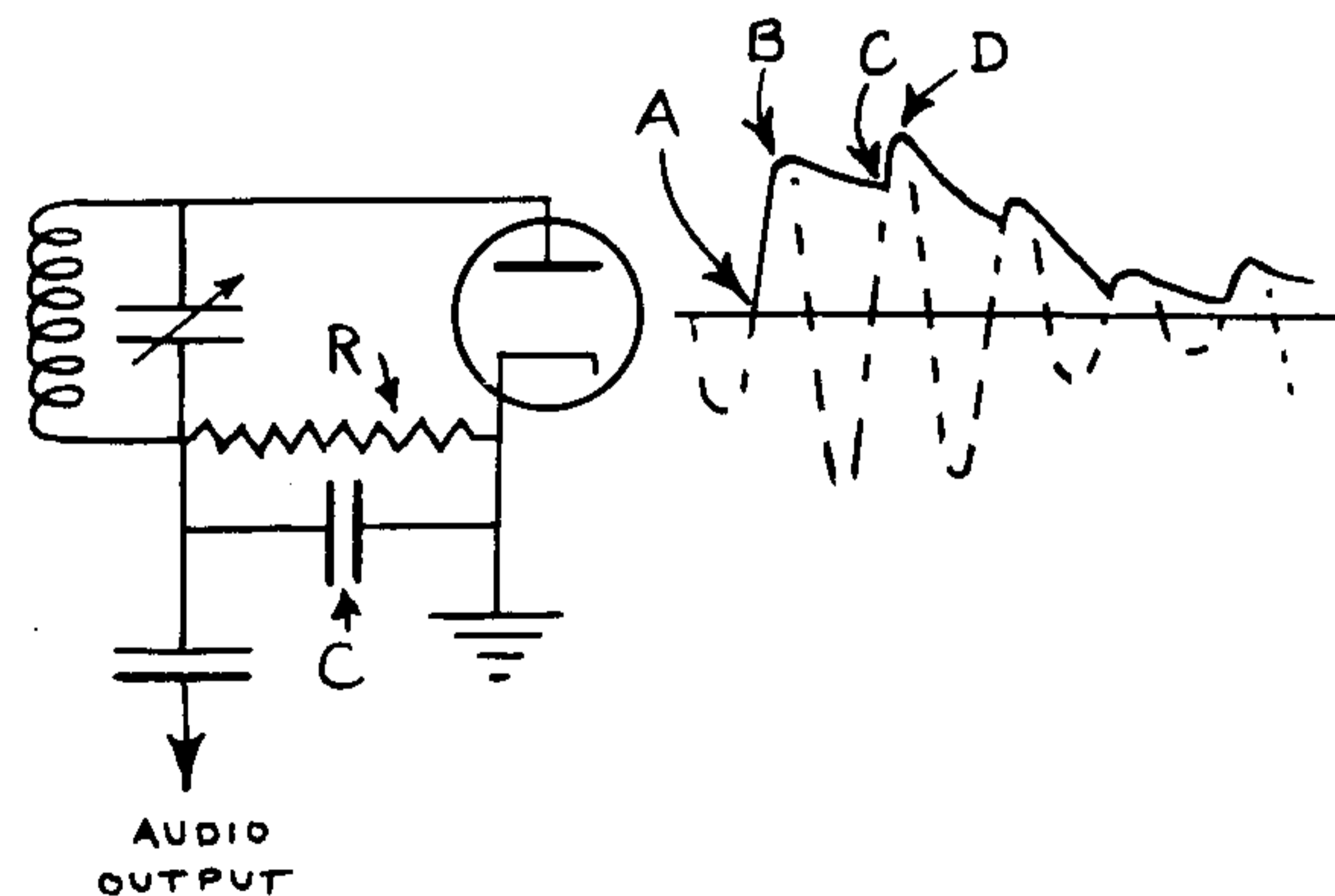


Fig. 44. Diode detector circuit.

The following is a more detailed description of the action of R, C, and the diode. The r-f signal is applied to the circuit as shown by the r-f voltage

in Fig. 44, while the output voltage across C is shown by the heavy line. Between points A and B on the first positive half-cycle of the applied r-f voltage, the condenser C charges up to the peak value of the r-f voltage. As the applied r-f voltage falls away from its peak value the condenser C holds the cathode at a potential more positive than the voltage applied to the plate and thus the condenser temporarily cuts off current through the diode. While the condenser thus cuts off current, the condenser discharges from point B to C, through the resistor R. When the r-f voltage returns to a positive value high enough to exceed the voltage at which the condenser holds the cathode, current flows again and the condenser charges up to the peak value of the second positive half of the r-f cycle at D. In this way the voltage across the condenser follows the positive peak value of the applied r-f voltage and thus produces the audio modulation. In the illustration the voltage across the condenser is shown jagged, however in actual practice the r-f component of the voltage across the condenser is negligible.

The condenser C should be large enough to smooth out the r-f or i-f variations, but should not be so large that it affects the audio voltage. This condenser usually runs from 100-350 μf .

The only disadvantages of the diode detector are that it doesn't amplify the detected signal and it draws current, thereby reducing the selectivity of the input circuit.

AUTOMATIC VOLUME CONTROL FROM THE DIODE DETECTOR

Automatic volume control, normally identified as "a-v-c", is provided in a receiver to prevent a change in the loudspeaker or audio output when the signal being received on the antenna is fading or when a set is being tuned from a weak to strong station signal.

This control is brought about by a circuit which reduces the r-f or i-f gain by increasing the negative

grid bias of the r-f and i-f stages when the signal increases. The a-v-c voltage is usually taken off the same diode load resistor as the audio component if the carrier is detected. Such a circuit is shown in Fig. 45. On each positive half of the r-f carrier, the diode plate is positive in respect to the cathode and the diode passes current. The diode current flowing through R_1 causes a voltage drop across R_1 that makes the left end of the resistor negative. This d-c voltage drop is then applied to the grids of the r-f and i-f tubes, through the filter R_2 and C_2 . When a strong signal is received the signal applied to the diode is increased and the voltage drop across R_1 increases. This increased voltage drop is then applied as an increased negative bias voltage to the i-f or r-f tubes and reduces the gain of these stages. Thus a strong or increased signal at the antenna does not produce as much output voltage at the detector as it would if a-v-c were not produced. Likewise when the signal at the antenna is small or decreases from a previous steady value, the a-v-c circuit acts in the opposite direction, applying less negative bias, permitting the gain of the i-f and r-f stages to increase and thereby increasing the strength of the signal at the detector.

The filter consisting of R_2 and C_2 is very necessary to prevent the a-v-c voltage from varying at an audio frequency rate. We learned under the diode detector that the voltage across R_1 and C_1 varies at the modulation frequency of the carrier, thus if we took voltage directly at this point without filtering, the gain of the receiver would vary at the audio rate and would smooth out the modulation of the carrier. For this reason the voltage is taken from across C_2 which by the action of the series resistor R_2 allows the condenser C_2 to charge and discharge at a very slow rate, lower than the audio frequencies but rapidly enough to compensate for fading.

In order to apply the audio signal detected to the first audio tube, condenser C_3 is inserted to couple only the a-c audio voltage. If C_3 was omitted the d-c or a-v-c would be applied to the audio tube and would probably be excessive, causing the tube to "block". (Tube would be inoperative).

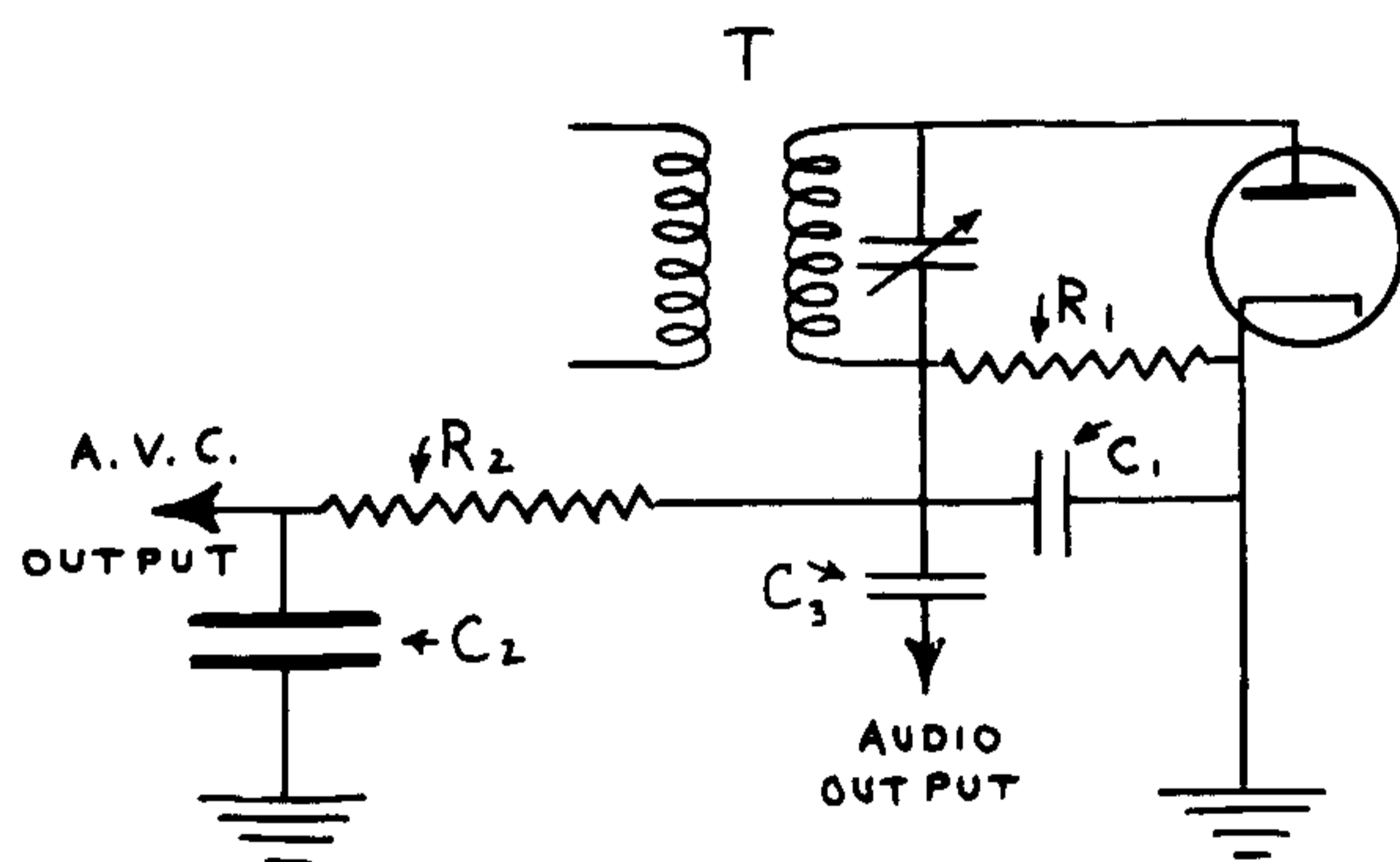


Fig. 45. Circuit for a-v-c from diode detector.

REVIEW QUESTIONS

1. Why are i-f circuits usually tuned instead of resistance or untuned?
2. What is the purpose of the detector?
3. What main difference do you see in the requirements for a diode detector as compared to a half wave rectifier used in the power supply, insofar as the filter is concerned?
4. What is the purpose of a filter to supply a-v-c to amplifier tubes?
5. Why is a condenser inserted between the diode and the first audio amplifier tube?

THE AUDIO AMPLIFIER

VOLTAGE AND POWER AMPLIFIERS

Since the voltages normally present at the detector are relatively small, it is necessary to further amplify them by an audio amplifier in order to change these audio voltages to sufficient sound energy for satisfactory listening enjoyment.

The audio amplifier consists of one or more stages of voltage amplification followed by a power amplifier stage. These must be built to reproduce faithfully all audio frequencies without noticeable distortion.

Amplifiers may be divided into two groups: Voltage and power amplifiers. A voltage amplifier is used chiefly to obtain greatly magnified reproduction of the input signal voltage without regard to power. Such amplifiers use high impedance plate circuit loads so as to obtain greatest voltage gain. The power amplifier uses an entirely different type of tube, which is capable of delivering a relatively large amount of power rather than amplification to its plate circuit load, which is usually the loudspeaker. In audio amplifiers, the power or output tube in the last stage is designed to give a considerable amount of audio power, while requiring but a negligible power from the input or exciting signal. The power amplification, which is the ratio of output power to power supplied the grid circuit, is consequently very high. Output tubes generally require a large grid voltage swing for full power output, so that the voltage amplification (ratio of output voltage to input voltage) is quite low. To obtain the necessary grid voltage swing for the power stage, one or more voltage amplifiers are used, employing tubes of high amplification factor to greatly increase the voltage amplitude of the signal. Although such tubes are capable of high voltage output, the power obtainable from them is small.

AUDIO AMPLIFIER COUPLING

In most audio amplifiers, the greatest part of the amplification takes place in the vacuum tube itself. With present high amplification tubes the question of gain in choice of coupling is not very important. The two most generally used audio coupling methods are by transformer and resistance coupling.

The transformer coupled amplifier uses a transformer to couple the plate of a tube to the grid of the following amplifier tube as shown in Fig. 46a. The varying current of the plate of the tube sets

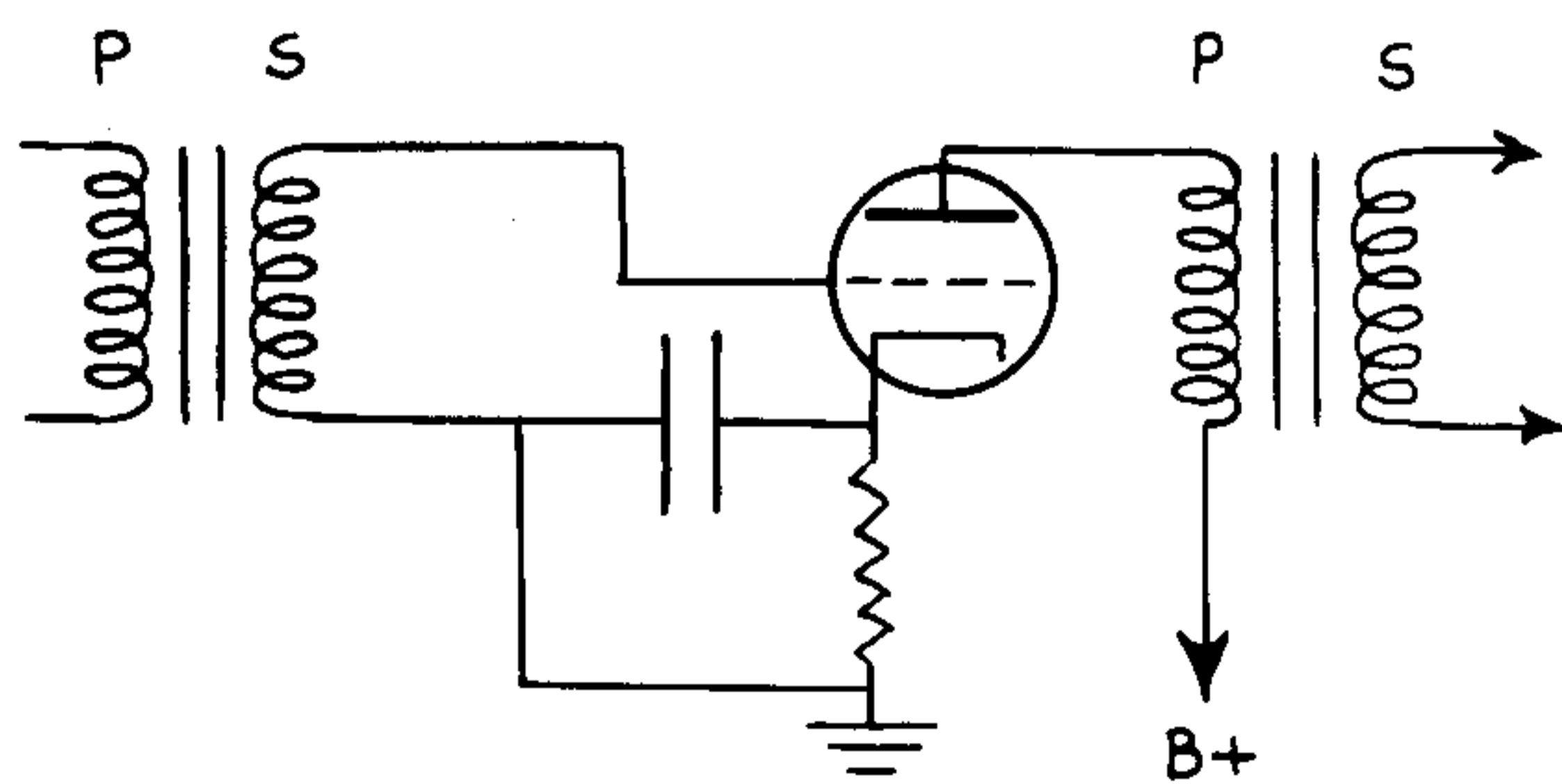


Fig. 46a. Transformer coupled audio amplifier circuit.

up a varying magnetic flux in the transformer which in turn induces a voltage in the transformer

secondary or grid winding. If the turns on the secondary are made greater than the turns on the primary, a voltage step-up will be obtained in this coupler. Thus if the transformer primary impedance is high in comparison to the tube plate resistance the amplification of the stage is approximately equal to the amplification factor of the tube times the turns ratio of the transformer. For this reason, if the same type of tube is employed, a transformer coupled audio amplifier requires less stages for a given total amplification than the resistance coupled type.

An amplifier is resistance coupled when the plate and grid circuits of successive audio tubes are connected together by means of a resistor in the plate circuit and one in the grid circuit, with the grid isolated from the plate insofar as the direct plate voltage is concerned, by a condenser as shown in Fig. 46b. A varying plate current, produced by a

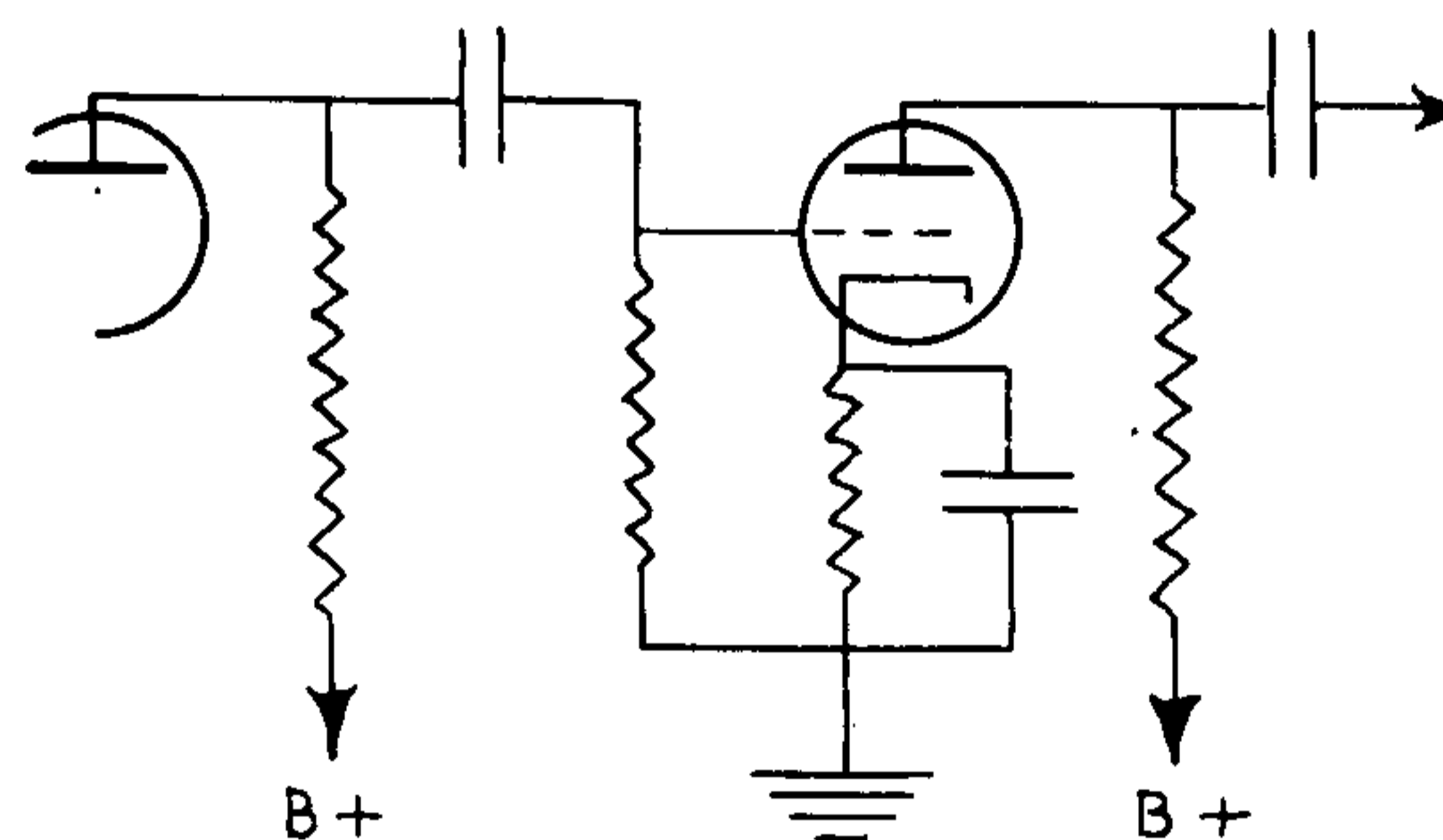


Fig. 46b. Resistance coupled audio amplifier circuit.

signal on the grid of the tube, passes through the plate resistor causing a varying a-c voltage to be developed which alternately charges and discharges the grid coupling condenser; causing a varying voltage in the grid resistor and grid of the succeeding tube. As there is no voltage step-up in this coupling system, all amplification is done by the vacuum tube. This makes it necessary to use more stages of resistance coupling than when transformer coupling is employed. The advantages of resistance coupling are that they are more compact and cheaper to build and that the amplification can be made very uniform over a wide band of audio frequencies.

THE POWER OUTPUT STAGE

Since the function of the last audio tube in the receiver is not only to amplify the signal voltages applied to the grid, but also to supply as much undistorted power to the loudspeaker as possible with a given input signal, power tubes are designed with special characteristics suitable for this purpose. It is power, not voltage, that is converted into sound by the speaker.

In voltage amplifiers, the plate load impedance is large to obtain as much of the usable amplification factor of the tube as is possible; however, with power output stages the load impedance is chosen for the best compromise between distortion and power output.

Since the moving coil of the dynamic speaker to which the power tube is coupled has a very low

impedance, usually from 2 to 10 ohms, this raises the problem of how to work such a loudspeaker from a power tube which has an a-c plate resistance of 2000 ohms or more. This is solved by the impedance transformer as previously studied. This transformer makes a 3-ohm impedance act as though

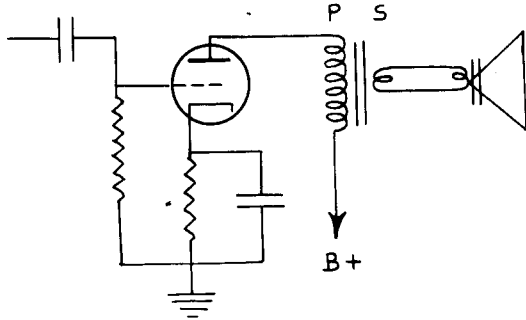


Fig. 47. Single power output audio amplifier circuit.

its impedance were any value desired by the choice of the proper turns ratio. A simple triode output amplifier is shown in Fig. 47. Two tubes can be connected in parallel in the same circuit arrangement to provide twice the power output of a single tube with the same value of grid signal voltage.

THE PUSH-PULL AMPLIFIER

A push-pull amplifier is used in audio output stages because it has several advantages over the single tube as shown in Fig. 47. A typical circuit is shown in Fig. 48. The secondary of the grid transformer is electrically center tapped and connected to ground; while each end of the winding is connected to the grid of a tube. Likewise each end of the output transformer is connected to the two tube plates and the winding is center tapped and connected to B+.

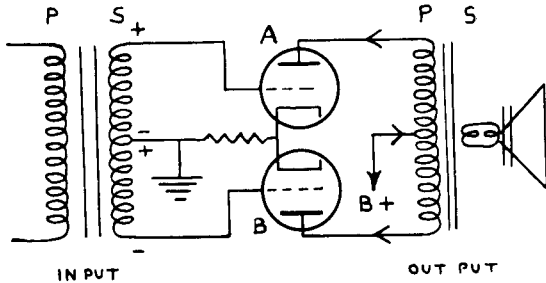


Fig. 48. Push-pull output audio amplifier circuit.

When no signal is impressed on the grids of either tube the plate currents in each tube are equal, and since they flow in opposite directions in the center tapped plate transformer, the magnetic flux caused by them cancel, and there is no magnetic field in the core due to the steady direct current component of the plate circuit. Now if a half-cycle of a-c voltage is induced in the secondary of the input transformer, the top tube "A" becomes positive with respect to the center-tap of the input transformer secondary.

This will cause the plate current of tube "A", which flows through the upper half of the output transformer primary, as shown by the arrows, to increase. At the same time, the plate current of tube "B" decreases an equal amount. Since these cur-

rents both flow in opposite directions in the output transformer primary, the effect of the changes add together as induced a-c voltage in the secondary winding. Under these conditions, the fields produced by the two halves of the primary winding no longer equal and neutralize each other but there is a resultant field in the direction determined by the direction of the flow of the larger current. On the next half-cycle of the signal voltage, the plate current of tube "B" increases while that of tube "A" decreases with the same effect as described above but in the opposite direction.

Due to the fact that the plate current variation in one tube is opposite in phase to the variation in the other tube, the sum of the two plate currents is nearly constant. This permits the omission of the cathode by-pass condenser when a common cathode biasing resistor is used. Another important consideration is the cancellation of second harmonic distortion between tubes which allows extremely low distortion operation. Considerably more hum can also be tolerated in the plate voltage supply to this type of amplifier without causing hum in the audio output because of the center tapping of the output transformer and the opposite flow of plate current for the two tubes.

PHASE INVERTER PUSH-PULL AMPLIFICATION

A phase inverter is used to provide resistance coupling between the output of a single tube stage and the input of a push-pull stage. The necessity of a phase inverter rises because the signal voltage input to the grids of a push-pull stage must be 180° out of phase, and equal in amplitude. That is when the signal voltage input to a push-pull stage swings one of the push-pull grids in the positive direction, it should swing the other grid in the negative direction by an equal amount. This out-of-phase input voltage can be obtained by an additional tube connected as a phase inverter.

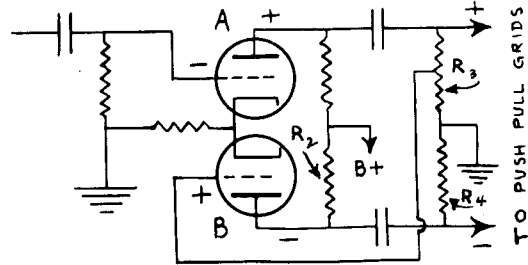


Fig. 49. Resistance coupled phase inverter, audio amplifier circuit.

Fig. 49 shows a simple phase inverter circuit in which the phase inversion is provided by tube "B". In this circuit the voltage output of tube "A" is applied to one of the push-pull grids. A portion of voltage output of tube "A" is also applied from the tap on R₃ to the grid of tube "B". The voltage output of tube "B" is then applied to the other push-pull grid. When the voltage output of tube "A" swings the grid of tube "B" in the positive direction, the plate current of tube "B" increases. This increases the voltage drop across the plate resistor R₂ and therefore swings the plate of tube "B" in the negative direction. Hence when the voltage output of

tube "B" swings negative, the voltage of tube "B" is 180° out of phase with the voltages of tube "A". The voltage output of tube "B" is made equal to the voltage output of tube "A" by adjustment of tap on R_3 . For example: If the voltage amplification of tube "B" is 20, the tap on R_3 is adjusted to supply 1/20 of the audio voltage across R_3 to the grid of tube "B". The audio voltage across R_4 is then made equal in amplitude to the audio voltage across R_3 .

AUDIO MOTORBOATING

Audio motorboating is evident by the setting up of a low frequency audio oscillation which sounds like a motorboat engine when reproduced by the loudspeaker. This is found especially in resistance amplifiers when using weak "B" batteries or a defective power supply.

Coupling in the power supply between various amplifier circuits is the most frequent cause of motorboating. This can usually be eliminated by placing a filter choke or resistor to the plate circuits and by-passing it with a 2 to 10 mfd. by-pass condenser. Merely placing a large condenser across the B+ lead to the various amplifier stages will also help.

FILTER CIRCUITS USING R-C NETWORKS

Fig. 50 shows the effect of placing condensers and resistors in audio circuits to alter the "frequency response" of the amplifier. The overall result is to alter the tone of the reproduction.

Remembering that the ability of a condenser to pass a-c voltage increases as the frequency of the voltage increases, it is evident from the diagrams what will happen by placing condensers in an audio amplifier.

Fig. 50a shows that the low frequencies are not passed on to the tube grid as well as the high frequencies, when the coupling condenser is too small with respect to the resistors on either side (plate and grid).

The above is the common arrangement of resistance coupled audio amplifier where C_1 is the coupling condenser and R_1 is the grid resistor.

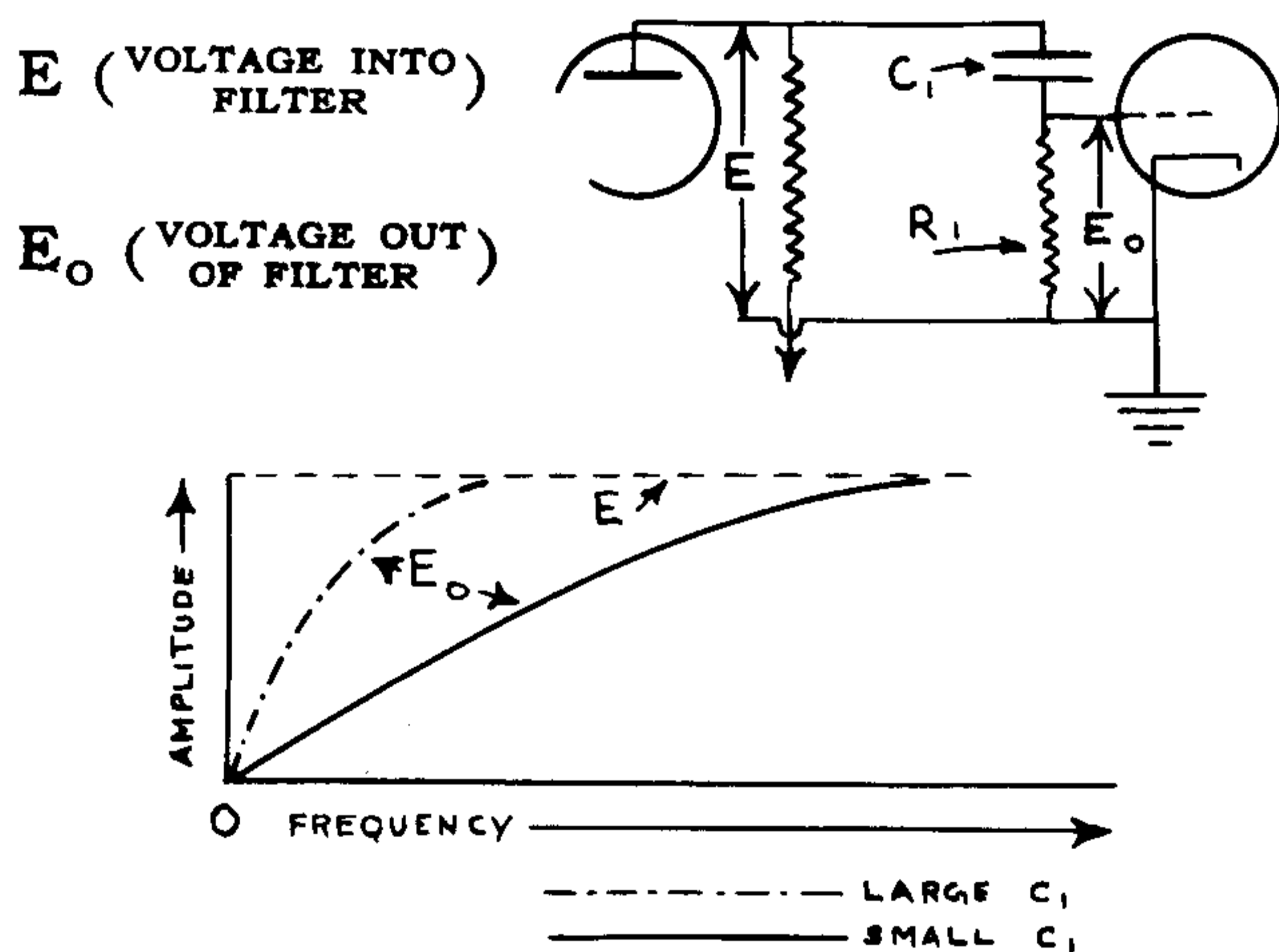


Fig. 50a. Effects of audio coupling condensers.

Fig. 50b is a typical tone control circuit. Here the condenser C_2 is directly across the line circuit in series with a resistor R_2 . R_2 may be variable. At some high audio frequency, C_2 would appear as

a short circuit, not allowing any high frequencies to pass. With resistance in series with the condenser, the high frequencies cannot become totally short circuited. With variable resistors on tone controls, the more resistance that is inserted the less the high frequencies are attenuated.

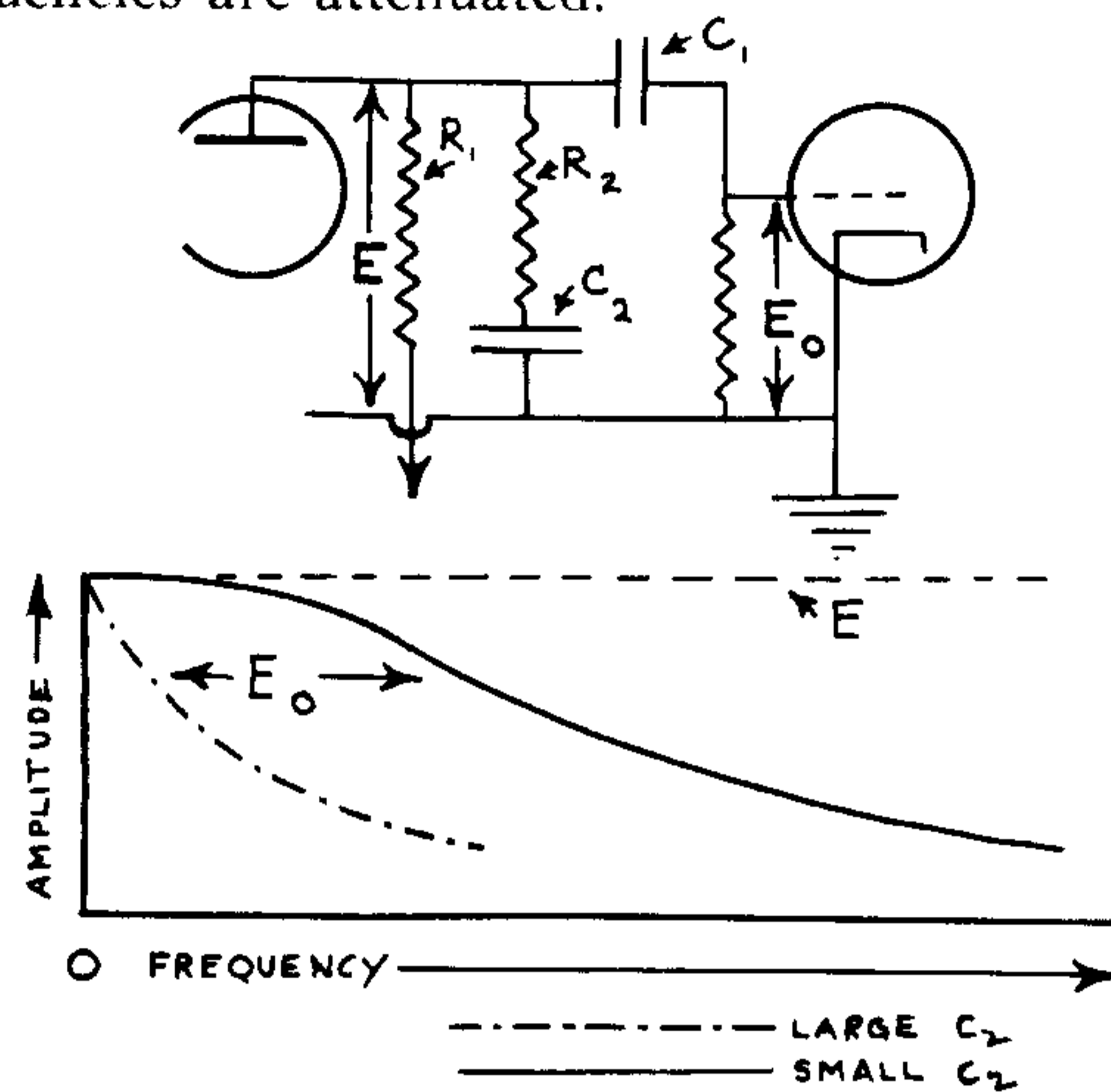


Fig. 50b. Effects of condensers and resistor, shunting audio circuit.

This is a form of the fixed or variable tone control where R_1 is the plate resistor, C_1 the coupling condenser large enough to have negligible reactance, R_2 and C_2 are the tone control circuit.

Fig. 50c shows the arrangement of condenser and resistor for bass compensation on a volume control. Here the condenser is across part of the control with

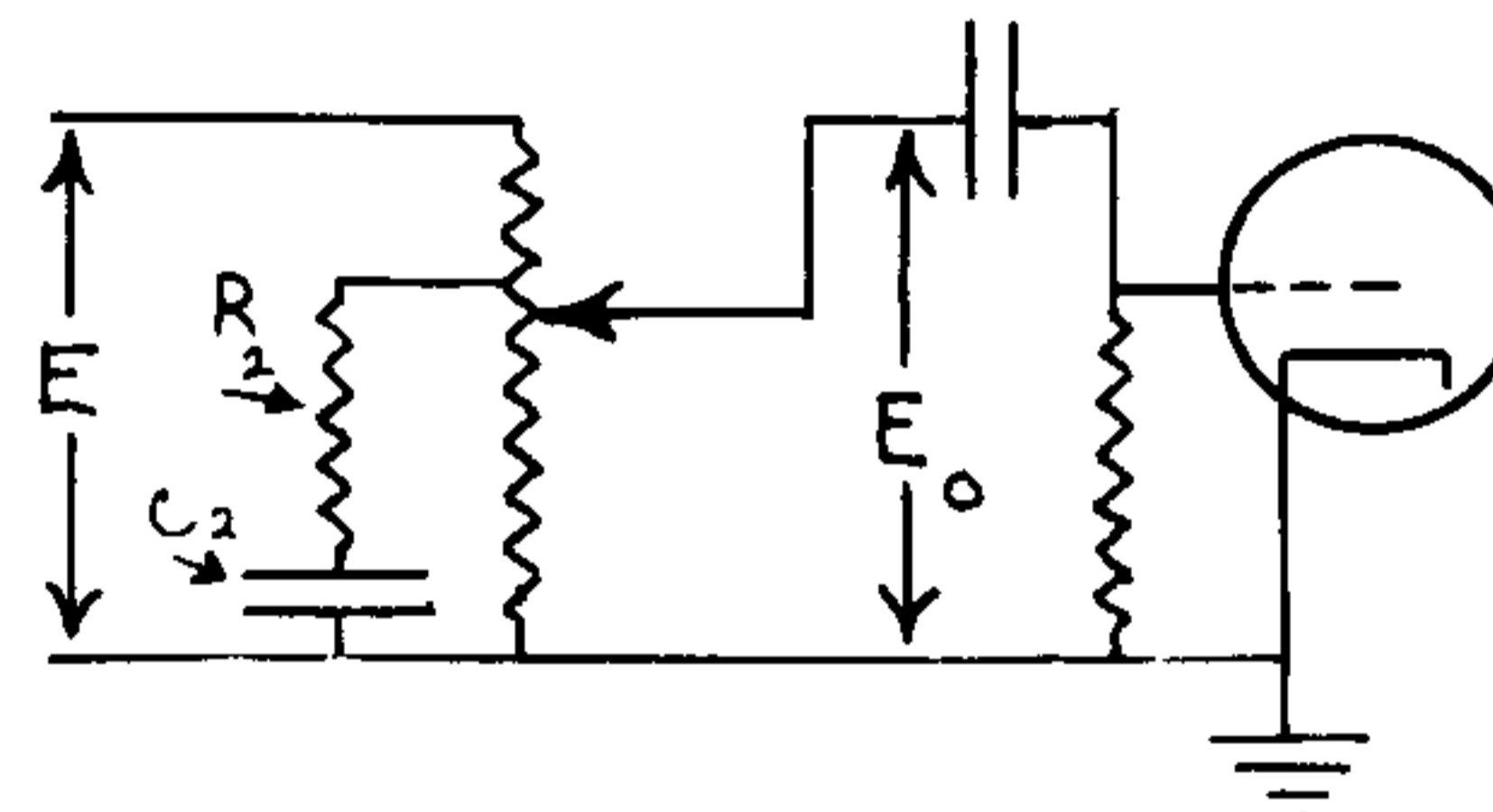


Fig. 50c. Circuit for bass tone compensation on volume control.

a resistor in series. When the control is turned for lower volume levels, the moving arm falls into the section of the control across which the condenser and resistor are connected. The effect is the same as in Fig. 50b.

Fig. 50d shows the arrangement of condenser and

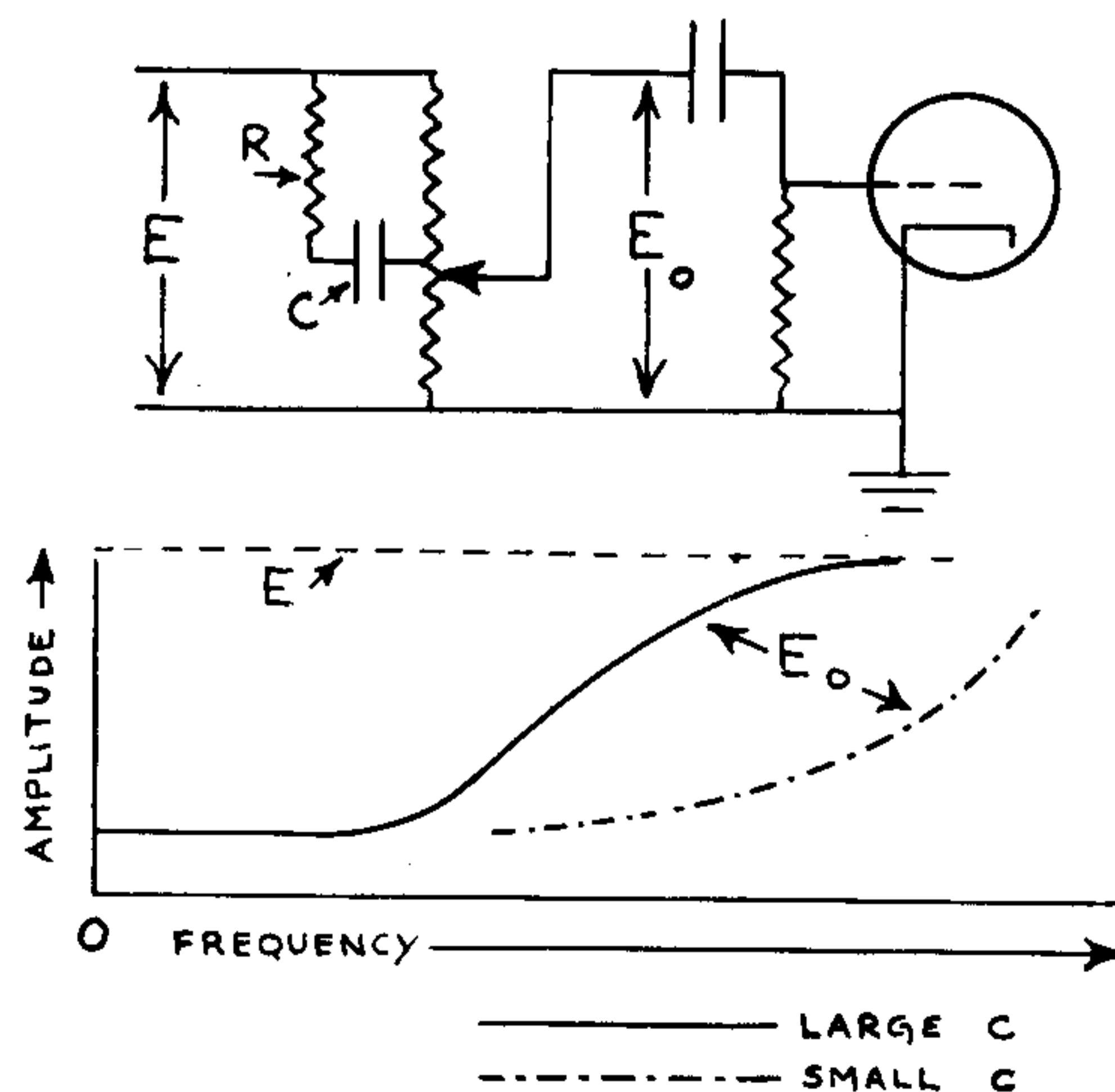


Fig. 50d. Circuit for treble tone compensation on volume control.

resistor to increase the high frequency response of the amplifier. Instead of being across the line, they are series with the line. Due to the characteristic of the condenser to pass more current as the frequency increases, more high frequencies will be passed on to the amplifier than low frequencies when the value of the condenser is not too large. The series resistor is inserted to limit the magnitude of the high frequencies passed.

It is customary to call circuits that pass high frequencies and not low frequencies "High Pass" circuits and conversely those that pass low frequencies and not high frequencies "Low Pass" circuits.

THE LOUDSPEAKER

The only type of speaker commonly used in broadcast receivers today is the moving coil type. This is built as the electrodynamic or the permanent magnet (PM) type speaker. The moving coil type

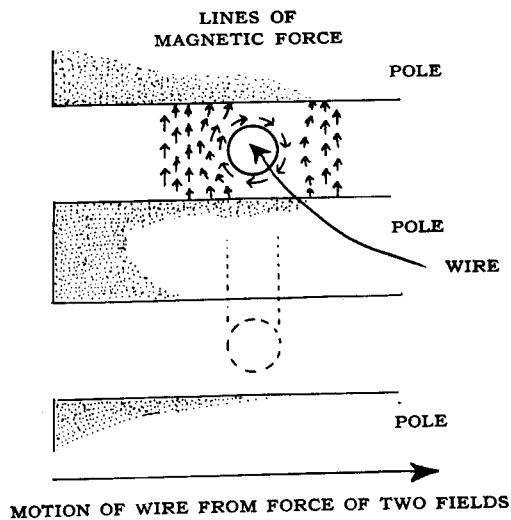


Fig. 51. Action of dynamic loudspeaker.

of speaker consists of a very small and exceedingly light cylindrical coil of wire called the moving coil or voice coil, through which the audio currents flow from the output transformer. Due to the fact that this coil has to be very light, it can only have a

few turns of wire which makes it correspondingly of low resistance and impedance. This voice coil floats in an intense magnetic field in a small circular air gap; the magnetic field either being supplied by a permanent magnet or an electromagnet energized by the power supply unit. Any small current flowing in the voice coil produces a varying magnetic field of its own. The action of the permanent strong field and the varying field of the voice coil moves the voice coil in and out of the circular air gap. The voice coil being fastened to a cone, vibrates the cone and causes sound to be reproduced.

The permanent magnet (PM) speaker has certain advantages over the electrodynamic speaker in that it is more compact, smaller and therefore has less weight. The electrodynamic speaker requires from 4 to 10 watts of power to properly magnetize the field, and this additional energy must be supplied by the power supply. (PM) speakers are less troublesome in service because they do not have a large coil which is liable to open up or burn out by overload current.

The basic principle of dynamic speaker operation can be understood better by noting the diagram Fig. 51.

Two sets of lines of magnetic force are produced, one a steady condition supplied by the field magnet, whether PM or electrodynamic. The other, produced by the voice and music currents flowing through the voice coil, producing a field surrounding the wire. These two fields are indicated by the arrowed lines. When the voice coil current reverses, the lines reverse their direction around the wire only.

Remembering that like magnetic forces repel and unlike attract each other, it can be seen that the direction of the lines on the right side of the wire are unlike those of the field magnet and the wire will move to the right. The magnetic lines of the field are, in a steady state, in a straight line and want to stay that way. Since the wire field upsets this condition, the field lines, attempting to straighten out, move the wire.

This principle is used to actuate motors, meters, etc.

REVIEW QUESTIONS

1. Why is an audio amplifier usually not "tuned"?
2. Why is the output tube usually not the same as the first audio amplifier tube?
3. Why is a push-pull amplifier so called?
4. What is the purpose of a phase inverter?
5. What would be the effect of an audio coupling condenser of too small a capacity?
6. What would be the effect if the field magnetism were removed from a dynamic loud speaker?

SUPPLEMENTARY INFORMATION

SHIELDING

In radio it is usually necessary to shield circuits from each other so that no interference could occur which would upset the functions that each circuit is to perform.

Capacity coupling between circuits can readily be prevented by enclosure in a grounded metal container. The metal case would short circuit and ground the electrostatic lines of force. Sometimes just a grounded metal plate, or screen, is all that is required between circuits.

Shielding for inductive coupling between circuits at high (radio) frequencies usually is accomplished with a simple metal grounded can, or plate. One such shield could suffice for both capacitive and inductive shielding. At these frequencies, the can or plate has appreciable inductance value and currents are induced into it just as if it were the secondary of a transformer. These currents (termed eddy currents) oppose those of the main circuit and keep the main circuit currents from passing through.

At lower (audio and power line) frequencies, a small non-magnetic shield can or plate does not represent much inductance and is therefore a poor shield. At these frequencies it is usually necessary to resort to magnetic materials for the shield.

Along the same lines, circuit currents and voltages must sometimes be guided by condensers and inductances. Condensers used in this manner are termed bypass condensers, and the inductances are termed chokes.

In viewing any electrical circuit, the complete circuit should always be borne in mind. For example, a vacuum tube amplifier input circuit is complete between the grid and cathode connections of the tube. If the d-c functions of the tube require a cathode resistor for bias, this resistor would have to be short circuited to complete the a-c path to the cathode. Placing a bypass condenser across this resistor accomplished this for the a-c circuit, but does not short circuit the d-c functions. The size of the condenser depends on the frequency to be bypassed, small ones for high frequencies, large ones for low frequencies.

PHONOGRAPH PICK-UP

There are a number of different types of pick-ups in use for reproducing phonograph recordings. The crystal type, however, due to its low price and excellent performance, is most generally found in the home receiver combinations.

The crystal pick-up makes use of the fact that some crystals, such as a Rochelle Salt crystal, will produce a voltage when a mechanical force is applied so as to twist the crystal. The pick-up crystal is constructed as a long thin strip of crystal which is firmly clamped at one end. The other end has the needle support attached so that sideways motion of the needle, following the modulation on the record, will twist the crystal slightly producing a voltage within it. The voltage is collected by means of two thin metal foil strips; one imbedded inside the crys-

tal while the other surrounds the outside of the crystal.

Nearly all crystal pick-ups require a frequency correction filter or a careful adjustment of the load resistance into which the crystal works because of the fact that the maximum voltage response is from a very low frequency to a frequency above 400 cycles. For this reason, if the pick-up is to work into a volume control circuit, careful consideration to the resistance value of the control must be given. Unlike transformer matching, the resistance of the volume control is not made the same as the impedance of the pick-up.

Record wear is unavoidable with pick-ups, due to the weight which is necessary to prevent the needle from leaving the bottom of the record groove. Wear of the walls of the groove is more serious than the wear of the bottom and is caused by needle wear, heavy damping of the pick-up and bad tracking of the pick-up arm. It is almost impossible to obtain good tracking with a straight tone arm, thus the more expensive pick-up units have a long bent arm.

The average crystal pick-up delivers from 1 to 2 volts and therefore can be connected directly into the first audio amplifier grid circuit. This is normally done by a switch which connects the pick-up across the radio receiver volume control at the same time it disconnects the detector from this circuit. The leads running from the pick-up into the receiver should be shielded and made as short as possible. The tone arm, phono motor and mechanism is usually connected to chassis ground to guard against hum pick-up.

THE CRYSTAL RECORDER OR CUTTER

Very similarly to the production of electrical energy from a mechanical flexure or twist of a Rochelle Salt crystal, we can also produce a mechanical recording device by applying a suitable a-c voltage to the crystal.

The crystal cutter consists of a Rochelle Salt crystal, held firmly at one end to a light metal case, but free to twist or move torsionally at the other end. This free end has clamped to it a simple bearing and needle holder. The bearing is normally of rubber, which allows some damping of the unit. An a-c voltage from the output of an amplifier is applied to two conducting surfaces of the crystal and then the mechanical twist or horizontal vibration is proportional to the frequency and amplitude of the voltage. This horizontal vibration of the needle cuts the surface of a record so as to record faithfully the frequency and amplitude of the voltage applied to the cutter.

About a watt of electrical output is normally used to satisfactorily operate a crystal cutter and this is coupled from the power output tube of the audio amplifier through a suitable impedance matching output or cutter transformer. A special recording needle is used for this purpose due to the fact that most home recording records are not pregrooved and the cutter must cut the groove as well as modulate it.

TEST EQUIPMENT

TEST OSCILLATOR

This item is one of the important pieces of equipment necessary to service radio receivers. It is a miniature broadcasting station. Its value lies in the fact that it can be set to any pre-determined frequency and signal strength not available from stations on the air.

Its usage is primarily for aligning receiver circuits and for analyzing trouble in any of the circuits. Anyone using a test oscillator must get acquainted with the limitations and capabilities of his own unit. Since oscillators are available which range in price from \$20 to \$4000, it's obvious that their qualifications will vary as to accuracy in frequency calibration, amount of signal output, and degree of accuracy in attenuating the output, frequency coverage, type of modulation, versatility for use with cathode ray oscilloscopes, etc.

The type usually used by service men consists of a shielding metal case enclosing the tubes and circuits of the oscillator. The dial is calibrated in kilocycles and megacycles divided up into several separate bands. A band switch changes bands and an output attenuator (volume control) is used to control the amount of signal output. There is usually a switch to cut the modulation (usually 400 cycles) in or out. The output leads are shielded, because the oscillator being a miniature broadcasting station, can "send" its signal through space just like any broadcast station, and it is desired to keep the signal in the bounds of the circuits and receiver being worked on. If it were allowed to radiate into space, there would be no way of knowing how much signal was being applied to circuits under test and varied interference conditions would arise.

Some of the earlier types were all battery operated, but the present types are usually all a-c.

VOLT-OHM-CURRENT METER

Probably this instrument is the least dispensable to a service shop. The average instrument consists of a metal case with a meter mounted on it. This meter is calibrated with scales to read Resistance (ohms) a-c and d-c voltage and d-c current. There are several ranges for resistance, voltage, and current.

The various ranges to be used are available by either plugging the probe leads into pin jacks marked for each range or turning a range switch to the range desired. If one wants to determine the voltage, for example, in a certain d-c circuit, the voltage is approximated and the range is selected such that the circuit voltage will not exceed the particular range selected. If one knows that the voltage may be in the neighborhood of 200 volts, a range must be selected to read as high as possibly 300 to 500 volts so as not to injure the meter.

In d-c circuits the polarity must be correct to the meter because if the leads are reversed to the meter, the current may cause damage to the pointer. Probe leads are usually colored red and black to conform to color code schemes that indicate black as minus or negative and red as plus or positive. At the point where the probes connect into the meter, the pin

jacks or connectors will be marked + and — and/or colored red and black.

One should also note the meter resistance. The most common in use are rated as 1000 ohms per volt to 10,000 ohms per volt. The resistance of the meter consumes power when placed in the circuit to be measured and may give a very incorrect reading if placed in a high resistance circuit where the meter resistance is so low by comparison that it shorts out the circuit. Most service notes list the voltage readings as measured on a 1000 ohm per volt meter.

Precautions

1. Never apply a-c to d-c portion of meters.
2. Be sure the meter range setting more than covers the range expected in circuits under measurement.
3. Meters are delicate in construction and must not be handled roughly.
4. Don't use current portion of meter to measure voltage circuits.

When set for the correct a-c voltage range, the meter affords an excellent output indicator to be connected across the voice coil of the loud speaker when "peaking" or aligning circuits to maximum.

CATHODE RAY OSCILLOSCOPE

The "X-ray" machine of the service shop is the cathode ray oscilloscope. With this instrument, many of the functions going on in radio circuits can actually be observed in picture form.

Its chief usage to radio service men is for alignment of receiver circuits which need a predetermined characteristic, usually impossible or requiring very long and tedious work with the usual meter indicating device. Such circuits as are used in television, FM and high fidelity receivers require the use of an oscilloscope.

As shown in our study of tuned (peaked, aligned, resonant) circuits, when a circuit is resonant to a certain frequency, other frequencies above and below this exact resonant frequency will still be passed. Sometimes it is desired to pass as few of these frequencies above and below resonance as possible, sometimes a great many are required. By using an oscilloscope to align the "band pass" (width of frequency range passed by one or all the tuned circuits) the desired width is indicated by the "curve" on the cathode ray tube screen.

For alignment, it essentially does this: If a radio or television receiver must amplify not only the frequency to which it is tuned, but frequencies a predetermined number of kilocycles or megacycles above and below as well, a signal generator feeds a signal to the receiver at various frequencies above, below and at resonance and a series of output meter readings can be plotted.

If a line is drawn through these readings plotted on paper, a picture of the "pass band" curve of the receiver is obtained. This would take a very long time. The oscilloscope does all of this in a split fraction of a second and allows adjustments of the alignment while being able to see what happens to the whole pass band curve at the same time.

As mentioned above, if a curve were to be plotted by an output meter, the test oscillator would have to be tuned for each reading. With the oscilloscope, this tuning of the test oscillator is necessary also, but again is all done automatically. In some, it is done by rotating the test oscillator tuning condenser back and forth with an electric motor. Modern test oscillators usually do the job electronically. Since the test oscillator is tuned back and forth a certain amount, it is actually frequency modulated.

TUBE CHECKER

The most common type of tube checker used today is the so-called "Dynamic Mutual Conductance" type, which means that the tubes are being checked under conditions nearly approaching actual operating conditions, to differentiate from those that only determine the strength of the electron stream emitted from the hot cathode or filament.

If the emission of a tube drops off far enough, the tube would be weak, dead, or inoperative, but there are many more considerations of a tube that would similarly affect its performance. In the emission test, if the value is below an accepted limit, the tube should be replaced, but if the value is acceptable, the tube still may not be good.

The "Dynamic Mutual Conductance" checker applies the rated voltages to the various elements of the tube being checked by means of switches. It also supplies an alternating voltage to the grid of amplifier tubes so that its effect on the plate current (the criterion of an amplifier tube's performance) is indicated. They automatically check the emission, and if it is low, the grid voltage has little effect on the plate current.

The procedure for checking tubes on a "Dynamic" instrument doesn't vary much for different makes. Instructions and charts are usually attached to each instrument. Read them.

The usual procedure is:

1. Turn instrument "on" and set the line voltage by means of the line adjusting knob (usually on same knob as "On-Off" switch) so that meter pointer coincides with "LINE" marker.

2. Refer to chart under tube type to be checked for control indexing. All controls are numbered, lettered or labeled. Set controls to proper index.

3. Insert tube in proper socket. Usually there is only one socket for each basing type unless there are pre-heating sockets. Turn "SHORT SWITCH" to "SHORT" position to determine if any short circuits exist, tapping tube lightly. Short circuits will be indicated by glow from the small neon tube built in the panel.

4. Press or turn "TEST" switch and note if meter reading falls within "OK" or reject region.

5. Double purpose tubes sometimes require checks for each section. This requires reindexing of one or several controls to test the second section. Refer to the chart, and proceed as before.

It must be remembered that a tube checker will not definitely determine that a tube is good, because the checker may not be duplicating the receiver operating conditions as to the frequency of the voltages applied to elements, circuit impedances and functions, such as oscillators. Generally, if the checker says a tube is bad, it is correct.

RMA COLOR CODES

RESISTORS

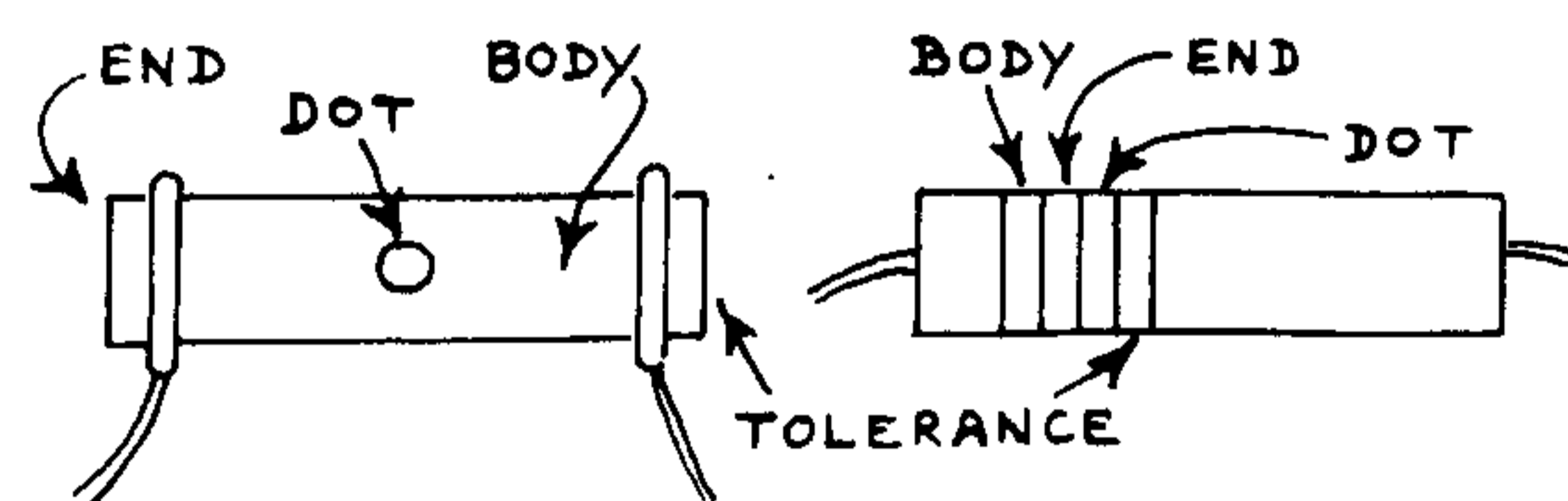
Tolerance of Values	Color
± 20%	No marking
± 10%	Silver (spot or ring)
± 5%	Gold (spot or ring)

The Radio Manufacturers' Association has adopted a universal marking for resistors so as to indicate their resistance. Four color indications are used: Body, End, Spot Color, or Band Coloring from end, with tolerance last.

The body color represents the first figure of the resistance value, the end color represents the second figure, and the dot or circle represents the number of zeros following the first two figures. The following table shows the values represented by the various colors:

Body Color	First Digit	End Color	Second Digit	Dot Color	Zeros
Black	0	Black	0	Black
Brown	1	Brown	1	Brown	0
Red	2	Red	2	Red	00
Orange	3	Orange	3	Orange	000
Yellow	4	Yellow	4	Yellow	0,000
Green	5	Green	5	Green	00,000
Blue	6	Blue	6	Blue	000,000
Violet	7	Violet	7	Violet	0,000,000
Grey	8	Grey	8	Grey	00,000,000
White	9	White	9	White	000,000,000

For values below ten ohms, body is always black. Read dot color as first digit and end color as second digit, the second digit being preceded by a decimal point, as 9.5, 6.5, etc.



Carbon resistors form an important part of present day receivers due to their low cost, compactness, and the wide range of resistance values obtainable. There are several important considerations for their use.

Power Dissipation Ratings: The sizes most commonly encountered in radio receivers are from 1/4 to 5 watt sizes. The dissipation rating must not be exceeded in continuous operation.

Voltage Rating

Rating (Watts)	Maximum Voltage
1/4	200
1/3	200
1/2	350
1 watt or over	500

The voltage rating may be used except when the wattage rating applies.

TOLERANCES

For production purposes the resistance rating is allowed to vary up to 20% of the rating assigned to it.

The heating of resistors in radio receivers, while chiefly due to the electric power dissipated in them, is also increased by their proximity to other warm or hot parts such as other resistors, transformers, and to lack of sufficient air circulation. For this reason a resistor of at least 25% greater watts dissipation over the calculated value should be used in the average radio receiver.

BALLAST RESISTORS

Receivers designed for operation on either 110 volt alternating or direct current do not use a power transformer. In such case, low voltage for the tube filaments is usually obtained from the 110 volt line by connecting the filaments in series. A suitable dropping resistance or more often a ballast resistor between the filaments and one side of the line is sometimes used.

A ballast resistor's function in the circuit besides dropping the voltage down low enough for the filaments, is to function as a current regulator by automatically varying its resistance so that the filament voltage and current are maintained at proper values in spite of possible variations in line voltages of 20 to 30 volts. Ballast tubes in most cases have taps so that one or more pilot lamps may be lit from this series dropping circuit.

All ballast resistor tubes are coded by the standard RMA code as follows:

- (1) The first letter designates the type of lamp.
K = 6-8 volts, 150 ma pilot lamps.
L = 6-8 volts, 250 ma pilot lamps.
- (2) The numbers designate the total voltage drop produced by the resistor including the pilot lamp voltages at .3 amp.
- (3) The last letter designates the particular octal base wiring employed.

RMA Color Codes — Transformers

I-F TRANSFORMERS

Blue — plate lead
Red — B plus lead
Green — grid or diode plate
Black — ground or diode return

A-F TRANSFORMERS — OUTPUT

Blue — plate lead
Red — B plus lead
Black — voice coil
Green — voice coil

POWER TRANSFORMERS

Black — primary (line)
Black and red — primary (line)
Red — rectifier plate or plates (high voltage)
Red and yellow striped — high voltage center tap
Green and yellow striped — filament 1
Brown and yellow striped — filament 2
Slate and yellow striped — filament 3
Yellow and blue striped — filament rectifier

TROUBLE ANALYZING AND REPAIRING

SUGGESTIONS ON CIRCUIT ANALYSIS FOR TROUBLE

In a complicated mechanical device it is usually possible to observe the details of operation and a defective part may be easily discovered by use of one of the senses, of smell, hearing, feeling, or seeing. In a complicated electrical device such as a radio receiver, however, the overall operation is easily checked, but the action of electric currents in their circuits is not usually apparent and trouble cannot be directly located. Yet a good circuit analyzer is able to locate defective parts quickly and accurately in a radio receiver. As a specialist in his line of work he must have a general knowledge of radio circuits and an understanding of their relation to the overall operation, but in addition he must be able to conduct tests, analyze the symptoms found, and locate the trouble. Certain tricks and short-cuts based on reasoning and experience enable him to work efficiently.

Approximately 95% of the radio receivers now being sold use the superheterodyne circuit, the remainder being tuned r-f receivers, so that an understanding of superheterodyne circuits is very important. R-f, i-f, and a-f amplifiers, converters, diode detection, and power supply circuits used in modern superheterodyne receivers have been described briefly previously. An intimate knowledge of the circuit connections and location of parts is, of course, important for a trouble shooter working on one type of receiver, but the serviceman in the field cannot possibly know the wiring of all receivers, and he must resort to a study of service notes and circuit diagrams in order to locate circuit components. An understanding of circuit diagrams is therefore of importance. The types of tubes and their socket connections give clues to a large number of circuits in a receiver without resort to connection diagrams. However, and since most superhet circuits have become fairly well standardized, it is sometimes possible to trace the chassis wiring. Special circuits such as automatic frequency control (a-f-c), or selective degeneration are not easily understood without technical knowledge of their action. With the arrival of television and even more complicated electrical circuits, the need for technically-trained men should increase.

The following lists some of the circuits and parts which may give electrical trouble in a radio receiver.

CIRCUIT CONNECTIONS

Wires broken, grounded to chassis, or shorting to other wires.

Poor connections, "rosin joints," loose pressure-contacts, open or broken welded connections, intermittent contacts.

Poor insulation on wire causing leakage through insulation in high humidity.

Static charges on plain rubber-covered wire in low humidity, causing noise in r-f and i-f grid circuits.

TUBES

Weak tubes having low emission, amplification, or gas.

Dead tubes, open heater, shorted elements or open connections.

Unstable tubes, overheating or "runaway" due to gas current.

Heater-cathode leakage causing hum.

COILS

Open or short circuited windings.

RESISTORS

Open or wrong value marked by color code.

If carbon resistors become overheated the resistance may increase or decrease in value.

CONDENSERS

Mica condensers — Open or shorted, or wrong color coding.

Paper condensers — Ditto, plus leakage current caused by humidity, giving particular trouble in high voltage, high impedance circuits (such as the audio coupling capacitor in a resistance-coupled amplifier). Poor or damaged wax impregnation is a contributing factor.

Electrolytic condensers — "Wet" condensers may overheat with high line voltage or due to defective construction. This type requires an open vent for release of gas. If unused for a long period of time, deforming of the electrodes may take place causing high leakage current for some time after power is applied. This may overload the rectifier tube or power transformer. This type of condenser is normally self-healing in case of voltage breakdown of the aluminum oxide film.

Electrolytic condensers — "Dry" condensers are not usually self-healing and the voltage safety factor is much higher. Failures are caused by breakage of impregnation seal and presence of salt or other impurities in atmosphere. "Open" filter condensers increase hum.

Gang tuning condenser may cause howl on short waves (12-18 mc) due to loose staking of plates, or loose shaft bearings. Older type gangs developed high resistance contacts on wipers due to corrosion. Many old sets have a characteristic noisy-tuning condition or instability from this.

SWITCHES

Power, band, tone or push-button switches may become defective mechanically, due to mishandling or wear. Adequate silver plating, contact pressure, and lubrication in r-f switches insure a reliable contact resistance of about .03 ohms. The indexing mechanism sometimes wears and does not properly locate the contact arm.

TRANSFORMERS

Shorted turns in power transformers cause excessive heating, and in an output transformer a loss in output and increased distortion. Open windings usually make a set inoperative.

Distorted tone in loudspeakers may be due to dirt or chips of iron in the air gap around the voice coil. Or the voice-coil or cone may become warped so that rubbing occurs in the air gap. Breakage of the cement joint in the structure of the voice coil or cone also produces audible buzz. In the new loudspeakers, the voice coils are wound on an aluminum strip and this prevents warping of the voice coil with changes in humidity. Static noise is sometimes found under low humidity conditions due to static electricity sparking between the voice coil and the loudspeaker field structure when the voice coil is not electrically connected to the loudspeaker frame. Humidity changes can also cause the cone to pull the voice coil part way out of the air gap so that poor efficiency, distortion, and lack of bass results. Hum balance with the hum-buck coil is also upset by this occurrence.

Loudspeaker field coils sometimes open up, particularly when wound with very small wire. High resistance field coils are found in small a-c receivers and in older receivers where the field coil was connected in parallel with the plate voltage supply.

VARIABLE RESISTANCE CONTROLS

These are more likely to be noisy when carrying d-c current. If the contact connectors are bent considerably, the internal pressure contacts on the resistance strip may become opened or intermittent.

SERVICE PROCEDURE

This list covers only a few of the difficulties which may be found in radio receivers.

In servicing old sets, the most common sources of trouble are likely to be component parts such as tubes, electrolytics, transformers, controls, etc., and in the line-up of circuits.

It is rather difficult to generalize and recommend a definite procedure to follow in analyzing radio receiver troubles because of the large number of possible sources of trouble. A preliminary check for plate voltage and for the more obvious things such as tubes, being O.K. and heated in the receiver, sometimes saves a lot of time. The common voltage supplies, and the plate and filament voltages may be easily checked by an analyzer or very roughly by shorting the circuits momentarily. But in cases where the trouble is hidden in a secondary or minor circuit, a starting check may be made of the loudspeaker operation, and then each preceding amplifier checked in succession back through the receiver, until the trouble is isolated in one stage.

If the first audio amplifier tube grid is touched, the audio amplifier should squeal, or, at least, a loud click should be heard. The converter and r-f amplifiers may be checked with a modulated signal of the correct frequency. If a "dead" stage or tube

is found, then the stage circuits are investigated for correct voltages and continuity.

The above description covers one way in which a systematic process of elimination may be used to lead directly to the source of trouble. After a preliminary check of the more obvious major circuits, the final amplifier was checked using the loudspeaker as an indicating device, and the tests continued back through the receiver. The opposite procedure is also useful in certain cases. For instance, in locating N.W.T. (noisy-when-tapped) trouble in a receiver, the noisy condition is usually first noted during line-up or when checking the overall sensitivity, and intermittent operation or clicks are heard in the loudspeaker or head-phones when the receiver chassis is tapped. The first tube, usually an r-f amplifier or converter, is pulled from its socket or its grid lead is removed and if the N.W.T. continues, the next tube is likewise removed from the circuit and the test repeated until the trouble is eliminated. This helps to isolate the noisy condition in one stage of the receiver and the wiring in this stage can then be checked.

In any method of systematically isolating circuit trouble in a receiver, it is desirable to start with a known condition and add or subtract circuits whose effects are understood until the faulty operation is found. It is sometimes helpful to eliminate all unnecessary circuits in isolating trouble. For instance, if a "ground" is found in a receiver on the positive plate supply circuit, the various plate connections may be opened in succession until the "ground" disappears. The same idea can be applied to an open circuit. If no plate voltage appears on the plate of a tube, a check is made at each preceding point in the circuit back to the rectifier filter until the open circuit is found.

In locating the cause of trouble in a radio receiver that will not work, it is necessary to locate the cause by a *process of elimination*.

A good trouble analyst, through experience and reasoning, will conduct a good portion of the procedure mentally, locating the trouble and making the necessary repairs or adjustments, aided by his equipment and tools.

The more knowledge he has about the fundamentals of radio, the physical aspects of chassis, parts, etc., and the equipment, the more efficient he should be at trouble analyzing and repairing of radio equipment.

TROUBLE ANALYZING AND CORRECTIONS OF A TYPICAL SUPERHETERODYNE RECEIVER

For other than obvious mechanical troubles, such as broken dial cables, binding controls, etc., a typical superheterodyne receiver will be "X-rayed" to show where typical troubles occur, the parts involved, the procedure in locating the trouble, and the adjustments or repairs necessary to correct. The procedure followed in locating trouble will be based on a logical "process of elimination."

Since the first indication that a radio is performing or not, good or bad, is the sound coming from it, the loudspeaker end is the most logical point to begin an analysis of trouble. The "process of elimination" then starts with the speaker, working back through the receiver, until the trouble is located and corrected.

The troubles and types of troubles reviewed do not, by any means, represent all trouble that might be found in any receiver. The G-E Model L630 Radio is used for the basis of this analysis and is representative of the average six-tube, two-band a-c superheterodyne.

Have service notes, equipment, etc., available. **Attempt to isolate trouble to the particular section affected by logical reasoning.** As an example, if the B band is O.K., but short-wave is dead, reasoning will tell you that the loudspeaker, power supply, audio circuits, etc., are not at fault. So, in the "process of elimination," a good portion of the procedure can be jumped and one can immediately concentrate on the stage most likely to be at fault. As in the above example, the circuits involved when the band switch is turned to S.W. should be checked, including r-f and oscillator-converter tubes.

Step 1 — Check loudspeaker if reproduction is distorted, fuzzy, buzzing or mechanical rattles are present.

Step 2 — Check external wiring, plug, connections, etc.

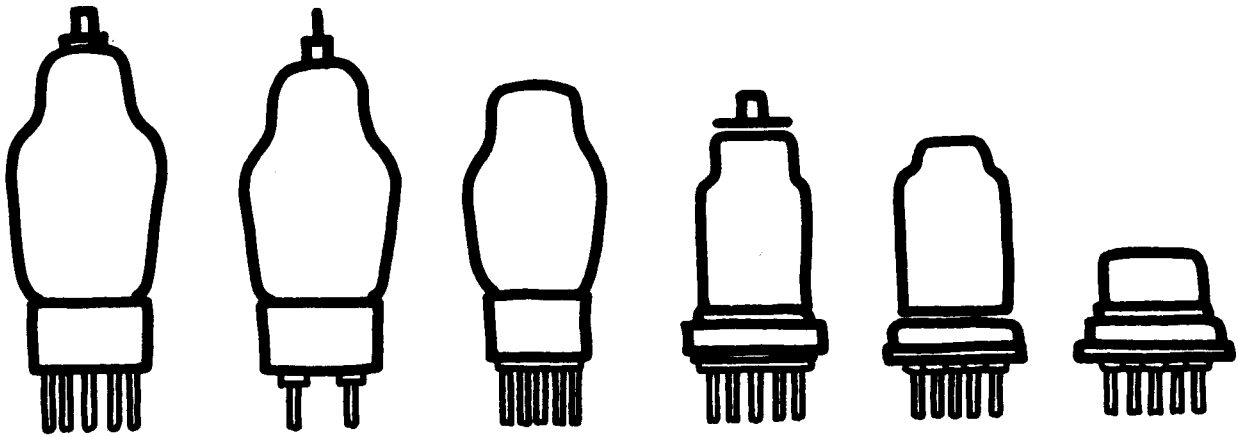
Step 3 — Check tubes. If trouble hasn't been located yet, it is usually necessary to remove chassis at this point. (See page 50).

Step 4 — Check chassis for shorted, broken wiring or parts visually. If trouble is just noisy when chassis is tapped, carefully tap around chassis until the trouble is located.

Step 5 — Check point to point voltages on volt meter. (Refer to service notes). On r-f and converter stages, rotate band switch to the various bands when checking voltages.

Step 6 — Make a stage-to-stage elimination to isolate the trouble, starting with audio output and the power stage. For detailed information on the technique of making a stage-to-stage trouble elimination check, see pages 51 through 58.

TROUBLE ANALYZING AND CORRECTIONS



TUBES

Symptom

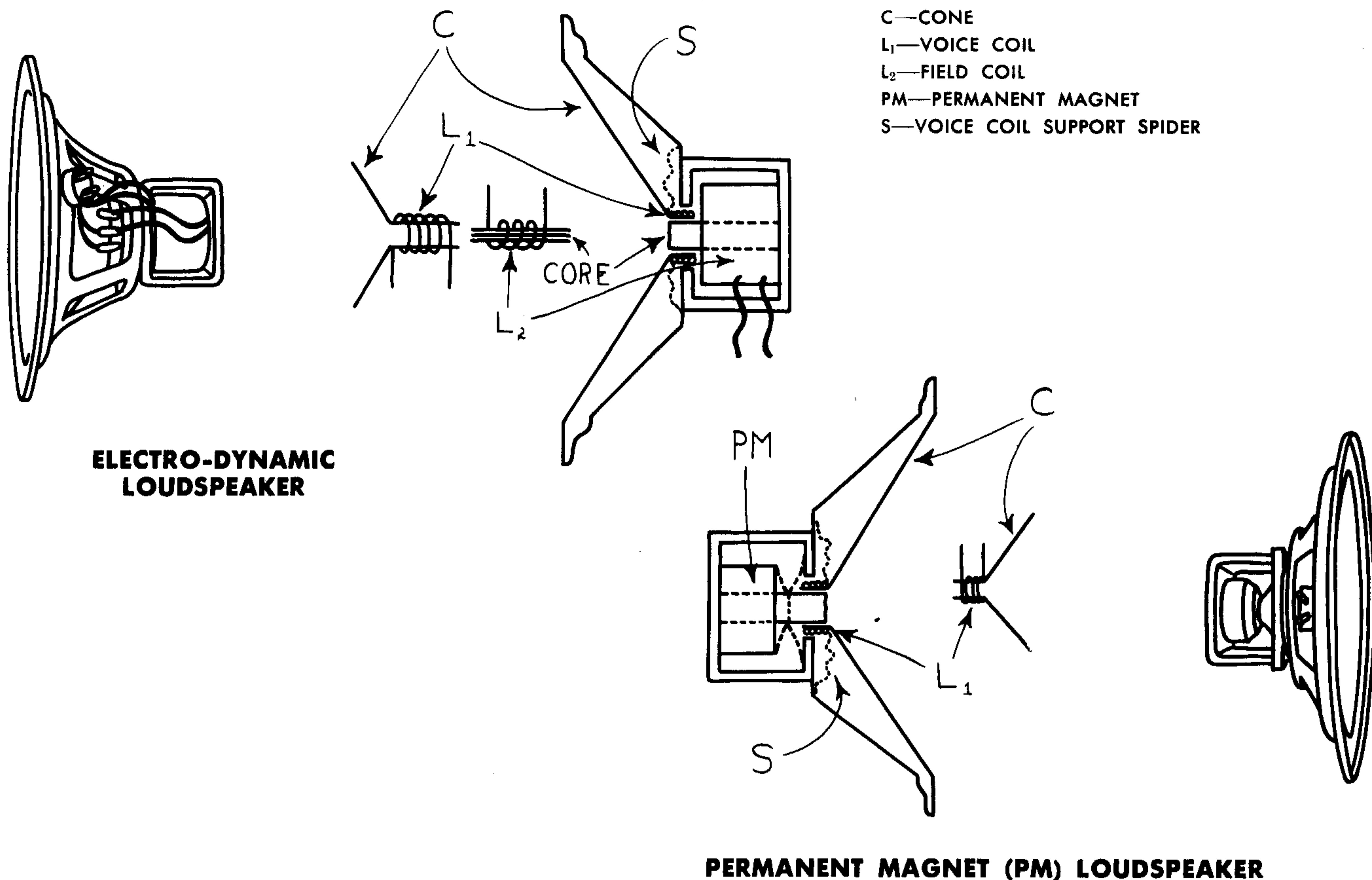
Dead
Intermittent dead
Noisy
Oscillation (Squeals)
Weak
Distortion
Noisy or dead when lightly tapped.
Burning resistors or other parts
Hum

Correction

Replace with good tube or tubes.

Preferred method of determining condition of tubes is by individual replacement with known good tubes. A reliable tube checker will indicate most tube troubles and will directly read current emission.

TROUBLE ANALYZING AND CORRECTIONS

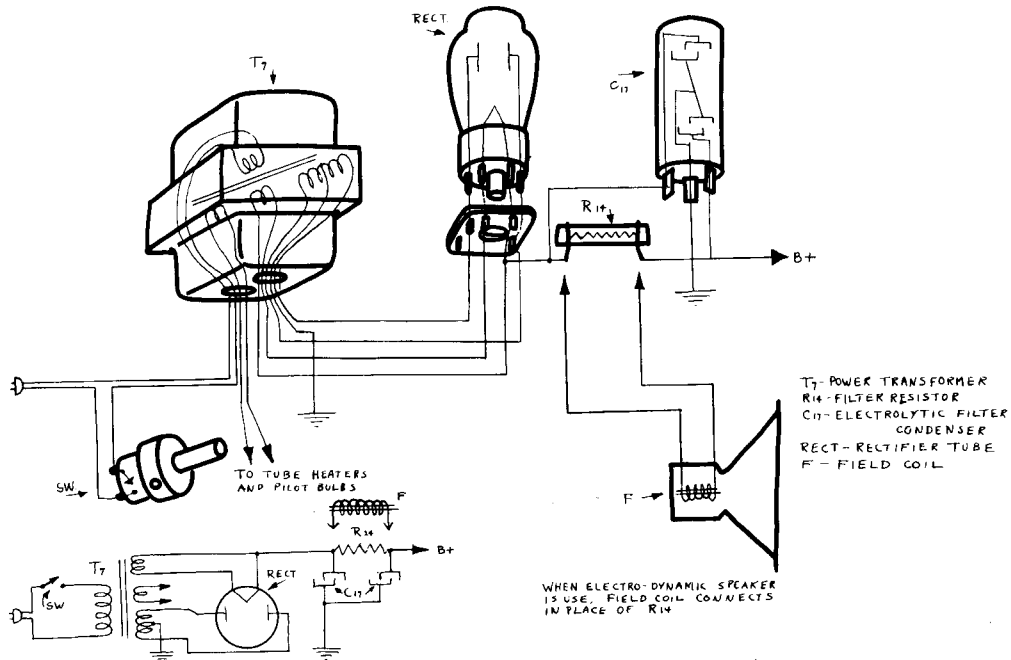


LOUDSPEAKER STAGE

Field coil is taken as part of the power supply, since it usually is part of the filter. This may be excepted in a-c/d-c models. If radio remains absolutely silent when output or rectifier tubes are clicked in socket—check speaker.

	Symptom Check	Probable Trouble	Remedy
P. M. Loud-speaker Dead.	1. a. High or infinite resistance reading on ohmmeter across voice coil connections (Disconnect voice coil from output transformer.) b. Low or zero resistance across voice coil.	Open voice coil or wiring to voice coil. (Also check plug connections.) Shorted voice coil leads or wiring thereto. (Also check plug connections.)	Change speaker cone, or repair connections. Remove short-circuit.
Distortion, Rattle, or Buzz	2. By ear. Variable audio oscillator, if available, fed to audio amplifier facilitates isolating the trouble.	a. Dirt in air gap around voice coil. b. Loose or excess cement around edge of cone or spider. c. Loose metal parts and mounting hardware.	a. Blow out with air stream. b. Clean off excess cement. May be necessary to replace cone due to inaccessibility. c. Tighten loose parts
General	When in doubt substitute duplicate or like rated speaker.		
Electro-dynamic speaker	All of above plus the following, if loudspeaker has hum-bucking coil.		
Hum	3. No change in hum by externally shorting hum-buck coil.	a. Shorted hum-buck coil or leads thereto. (Check on ohmmeter for correct resistance reading.)	Change speaker or clear short.

TROUBLE ANALYZING AND CORRECTIONS

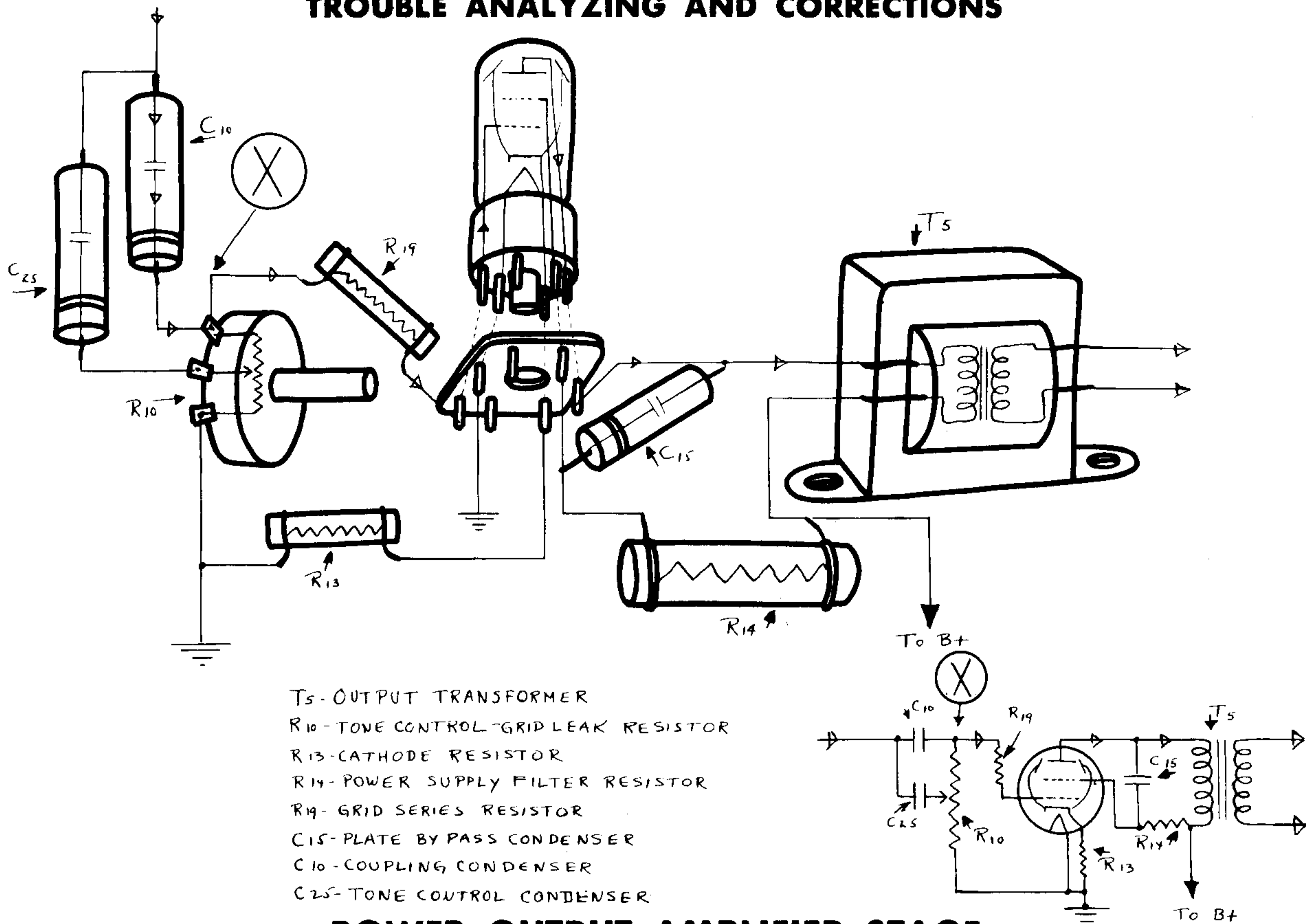


POWER SUPPLY STAGE

	Symptom Check	Probable Trouble	Remedy	
Dead	1. No "B" plus voltage across one section of filter condenser.	a. Open field coil or filter resistor or connections thereto. b. Shorted electrolytic condenser (check with ohmmeter).	a. Change resistor, speaker, or repair connection. b. Change filter condenser.	
	2. No "B" plus voltage at filament or cathode of rectifier tube.	a. Shorted electrolytic condenser. (Check with ohmmeter.) b. Open power transformer. (Check with ohmmeter or a-c voltmeter.)	a. Change filter condenser. b. Change power transformer.	
	3. No a-c to the pilot lights, tube filaments or rectifier plates.	Open a-c power switch. (Check with ohmmeter, power plug disconnected from power.)	Change a-c switch.	
	4. Rectifier tube plates get red hot.	Shorted electrolytic. (Check wiring, etc., thereto.)	Change electrolytic condenser.	
	Hum	5. Hum stops when like electrolytic is substituted across filter condenser.	Open electrolytic condenser.	Change electrolytic condenser.
		6. A-c voltage reading on a-c voltmeter not equal within about 10% as measured from B minus or chassis to each plate connection on rectifier tube.	Shorted or partially open section of power transformer. (Check with ohmmeter.)	Change power transformer.
		7. Low reading across filter resistor on ohmmeter.	Resistor changed value from overheating due to other troubles such as shorted tube.	Change filter resistor.
General	8. Power transformer excessively hot or smoking.	Shorted turns in power transformer.	Change transformer.	
	9. Hot or excessively warm electrolytic condenser.	Partially shorted electrolytic condenser.	Change condenser.	

Note: Since the power supply feeds all other voltage circuits and tube filaments, pilot lights etc., any shorts or partial shorts in these sections will be reflected back to the power supply. Sometimes it may be necessary to disconnect leads feeding other parts to isolate.

TROUBLE ANALYZING AND CORRECTIONS



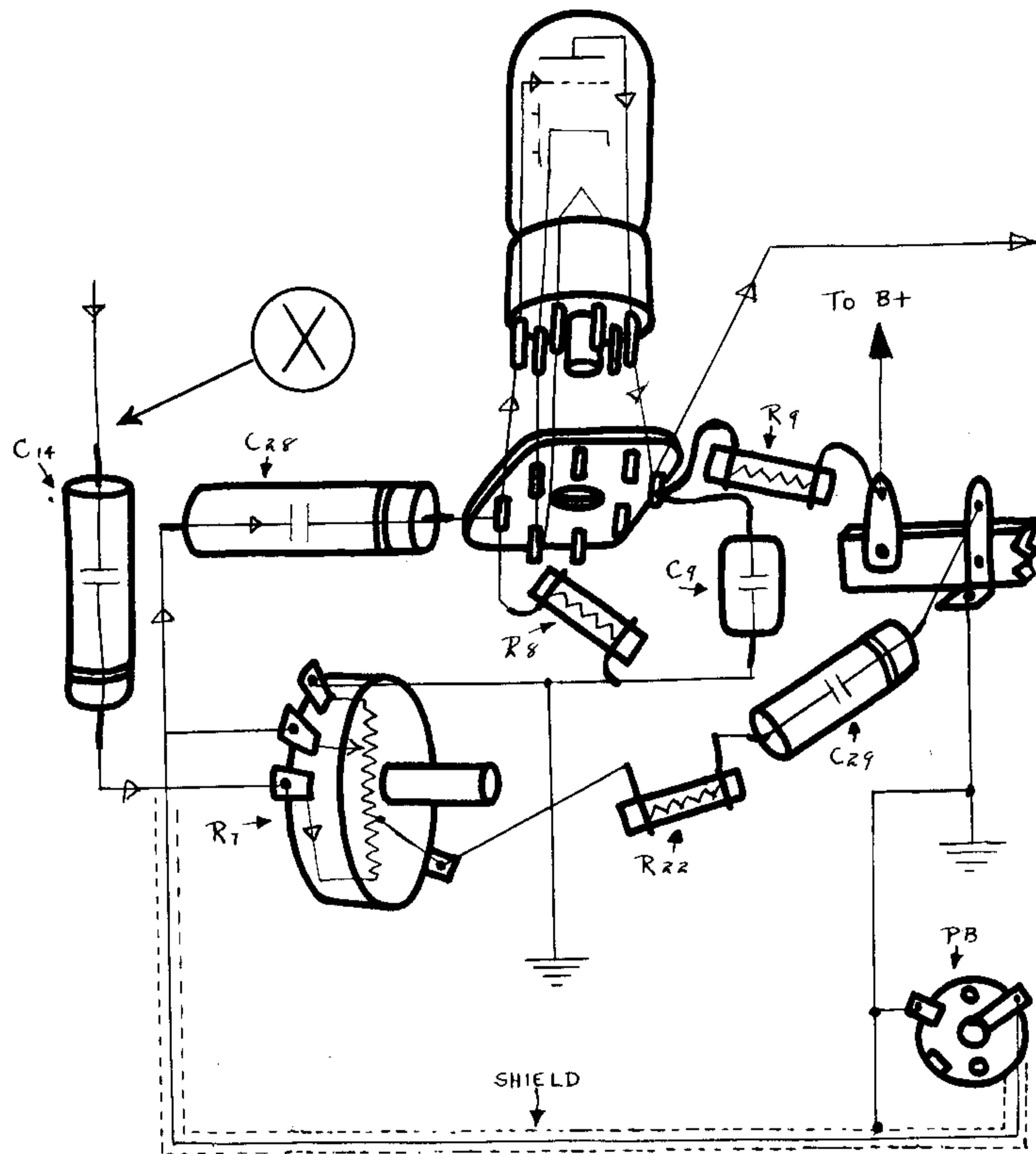
POWER OUTPUT AMPLIFIER STAGE

An audio signal from a signal generator applied between point (x) of the output stage and ground will indicate the condition of this section. Some service men derive their own short cuts, such as checking the preceding tube in and out of the socket to supply a "click" signal to the output tube to determine if the stage is alive or dead. For accuracy, a signal generator is preferred.

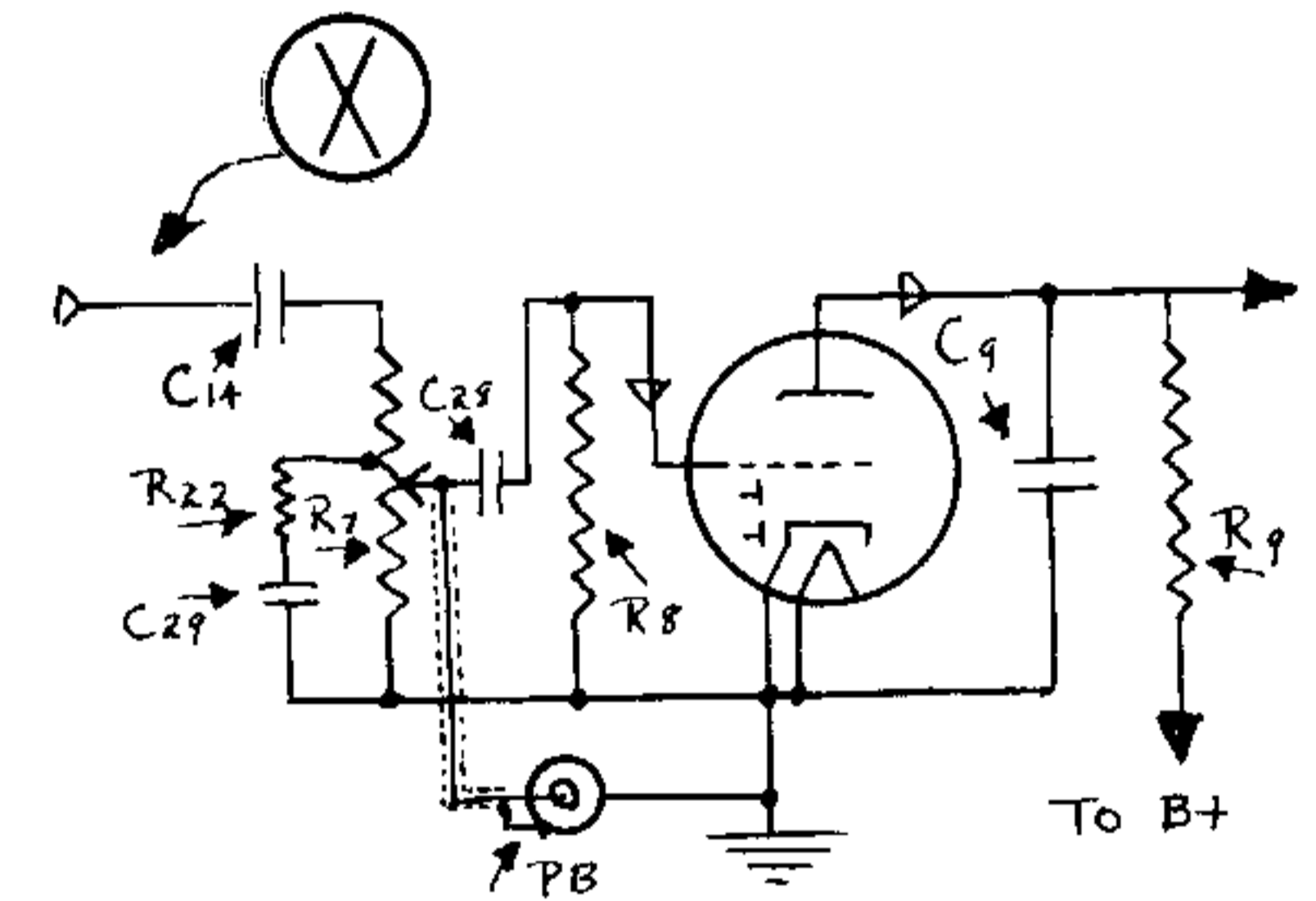
Symptom Check	Probable Trouble	Remedy	
Dead	1. No "B" plus voltage reading on voltmeter at tube plate connection.	Open output transformer. (Check resistance across primary and secondary with ohmmeter.)	Change transformer.
	2. No or low "B" plus voltage at tube plate on voltmeter.	Shorted plate by-pass condenser. (Check resistance across condenser, with one lead disconnected, on ohmmeter—should be infinite.)	Change condenser.
	3. Any "B" plus voltage on voltmeter at tube grid connection.	Shorted coupling condenser. (Check on ohmmeter as in (2).)	Change condenser.
	4. Stage alive with signal applied on tube grid but dead on other side of coupling condenser.	Open coupling condenser. (Check by substituting like condenser across.)	Change condenser.
Distortion	5. Distortion clears when like plate by-pass condenser is substituted across plate condenser.	Open plate by-pass condenser.	Change condenser.
	6. Variations of 1, 2, 3, 4.	1, 2, 3, 4.	Change indicated defective part.
	7.	Refer to power supply and speaker.	
	8. No "B" plus voltage reading on plate of one push-pull output tube connection.	Open winding on output transformer. (Check with ohmmeter.)	Change output transformer.

Path of audio signal through the amplifier is designated by ▷ ▷

TROUBLE ANALYZING AND CORRECTIONS



PB - PHONO INPUT TERMINAL BOARD
 R1 - VOLUME CONTROL
 R6 - GRID LEAK RESISTOR
 R9 - PLATE RESISTOR
 R22 - BASS COMPENSATION RESISTOR
 C14 - DIODE COUPLING CONDENSER
 C28 - AUDIO COUPLING CONDENSER
 C29 - BASS COMPENSATION CONDENSER
 C9 - PLATE BYPASS CONDENSER



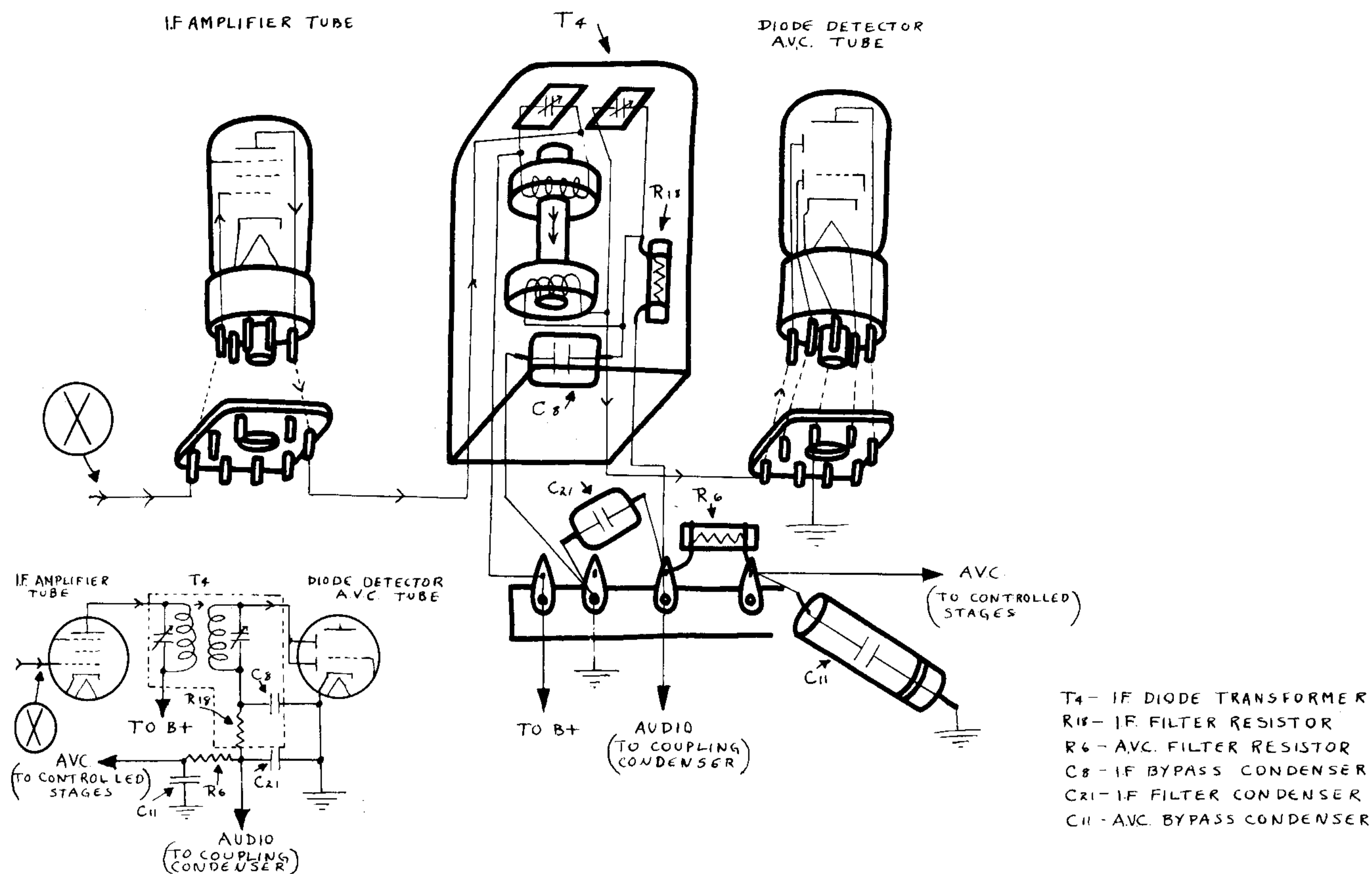
FIRST AUDIO AMPLIFIER STAGE

The condition of this stage can be checked by feeding a signal from a signal generator between point (x) connection and chassis.

Symptom Check	Probable Trouble	Remedy	
Dead	1. No "B" plus voltage reading on voltmeter at plate connection of tube.	Shorted plate by-pass condenser. (Check with ohmmeter across condenser with one lead disconnected. Should read infinite.)	Change condenser.
	2. Normal output by feeding signal from generator on grid of tube but not on other side of coupling condenser.	Open coupling condenser. (Check by substituting like condenser across.)	Change condenser.
Noisy Volume Control When Turned	Worn control. (With no signal, no voltage, should be read across control.)	Change volume control.	

Path of signal through amplifier is designated by

TROUBLE ANALYZING AND CORRECTIONS



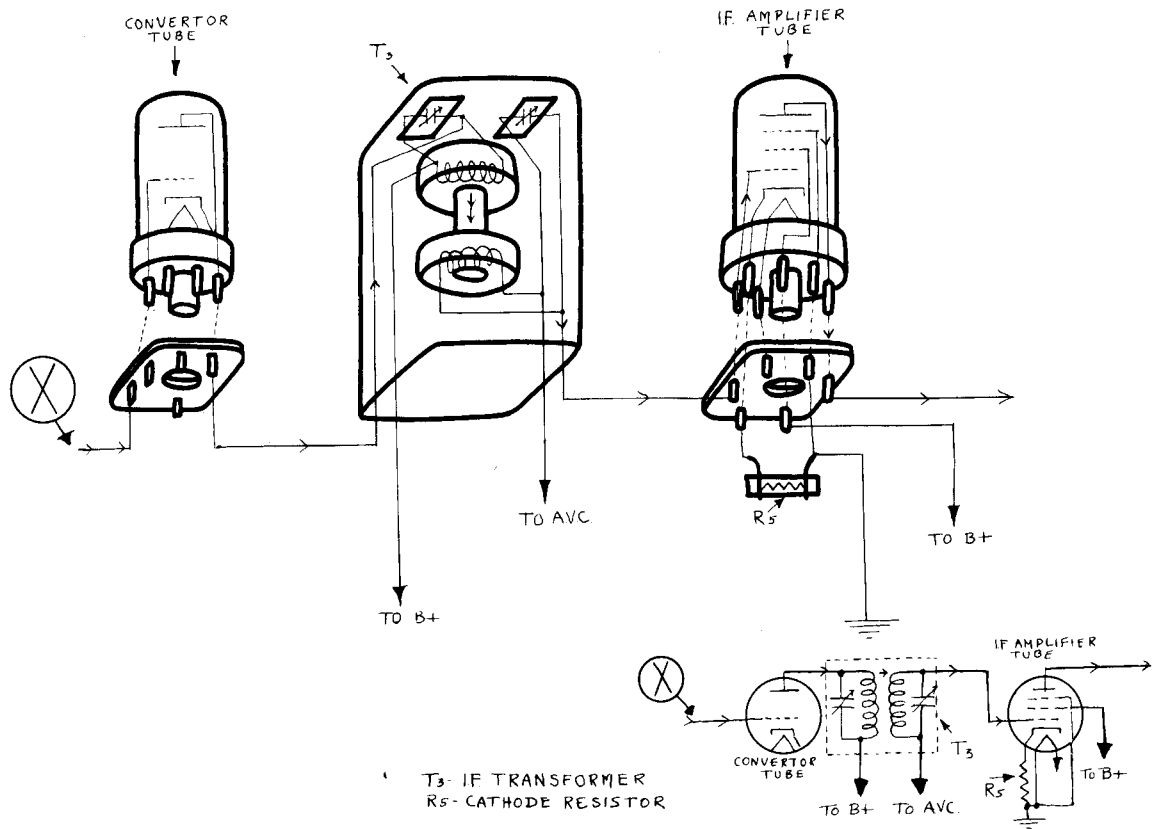
DIODE DETECTOR STAGE AND A.V.C.

This stage can be checked by feeding modulated i-f signal from signal generator between grid of i-f amplifier tube (x) and chassis. Since i-f signal and audio signal are separated here, alignment of tuned circuits is first encountered. Refer to service notes for alignment procedure.

Symptom Check	Probable Trouble	Remedy	
Dead	1. a. No "B" plus voltage reading at plate of i-f tube on voltmeter.	Open primary i-f transformer. (Check across winding connections with ohmmeter for correct reading.)	Change i-f transformer, or repair connections.
	b. same as "a."	Shorted plate filter condenser. (Check on ohmmeter with one lead disconnected—should read infinite.)	Change condenser.
Distortion	2. Low resistance reading on ohmmeter from a-v-c connection to chassis.	Shorted a-v-c by-pass condenser.	Change condenser.
Oscillation	3. Oscillation stops when like condenser is substituted across a-v-c by-pass condenser.	Open a-v-c by-pass condenser.	Change condenser.

Path of signal through amplifier is designated by > >

TROUBLE ANALYZING AND CORRECTIONS



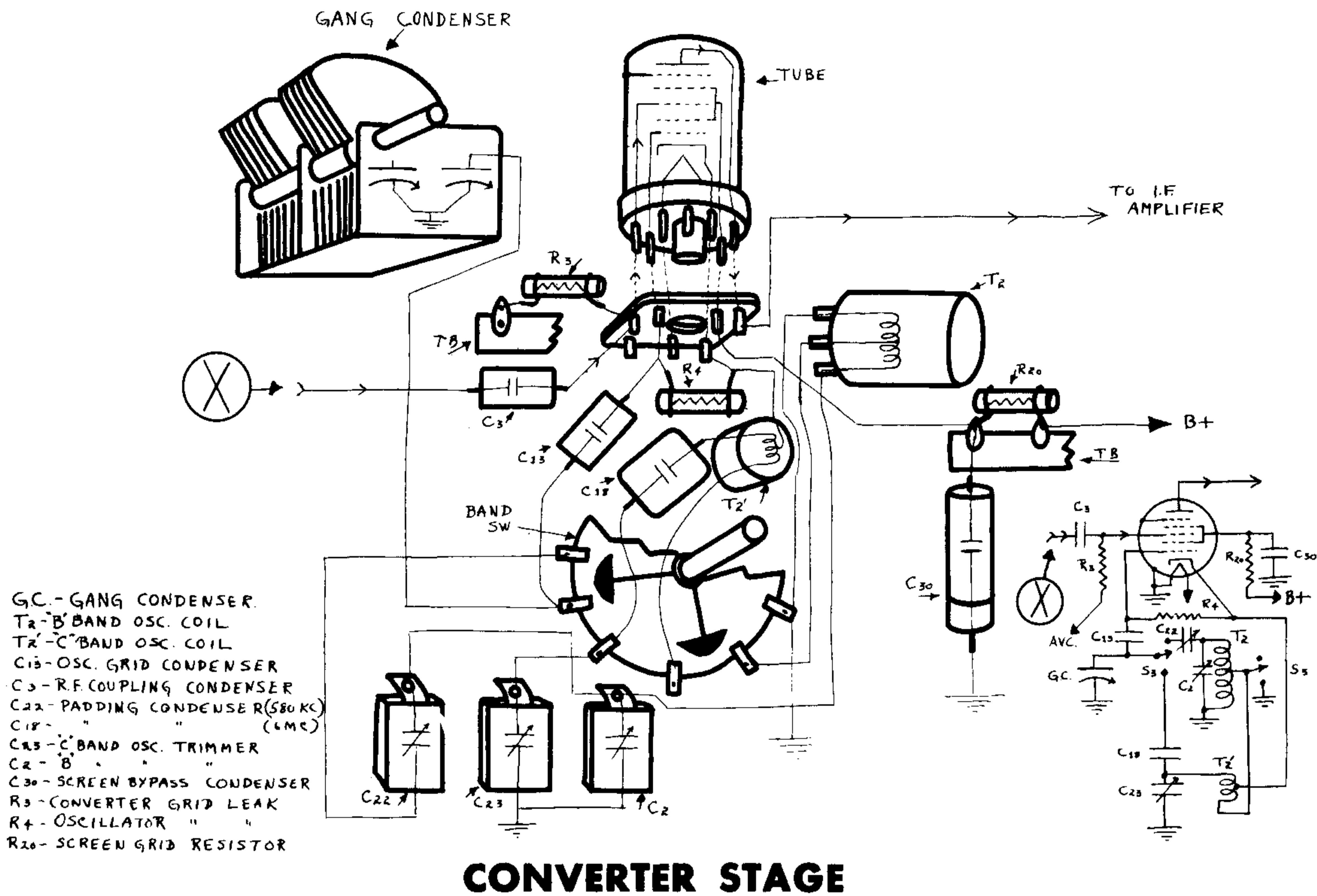
I-F AMPLIFIER STAGE

Condition of this stage can be checked by feeding modulated i-f signal from signal generator between grid (x) of converter tube and chassis.

Symptom	Symptom Check	Probable Trouble	Remedy
Dead	1. No "B" plus voltage reading at plate of converter tube on voltmeter.	Open primary on i-f transformer. (Check with ohmmeter across winding for correct reading.)	Change i-f transformer, or repair connections.
	2. No "B" plus voltage reading at screen grid of converter tube.	Shorted screen grid by-pass condenser (if any). (Check with ohmmeter across condenser with one lead disconnected. Reading should be infinite.)	Change by-pass condenser.
Weak	3. Check alignment per service notes, using output meter or similar device.		Realign

Path of signal through amplifier is designated by > >

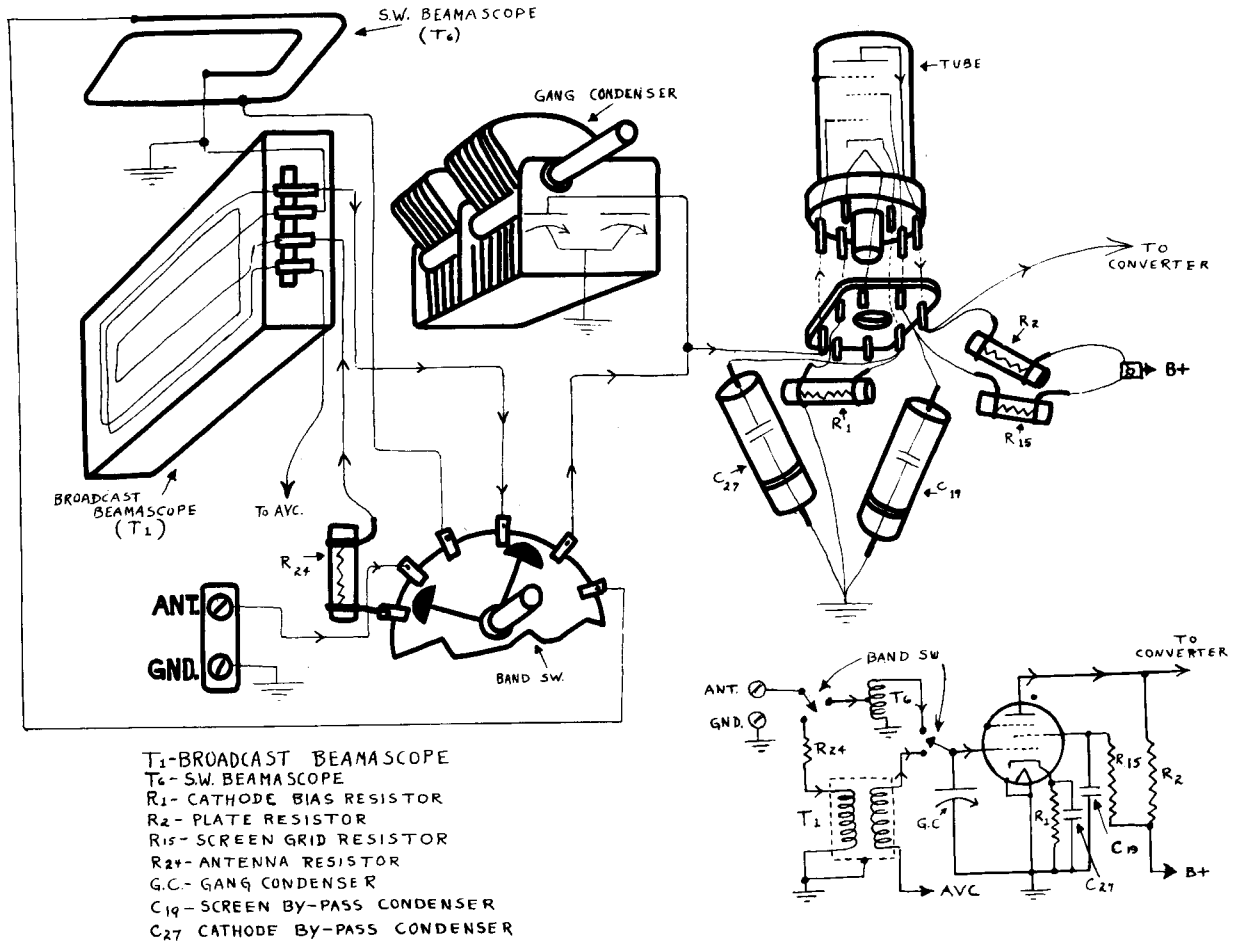
TROUBLE ANALYZING AND CORRECTIONS



Condition of this stage can be checked by feeding modulated signals from signal generator between point (x) and chassis. Since it is here that r-f is converted to i-f, it should be checked first to determine that it is passing i-f satisfactorily by feeding an i-f signal as covered under i-f, amplifier. If O.K. on i-f then feed r-f signal, tune receiver to signal being supplied by the generator.

	Symptom Check	Probable Trouble	Remedy
No R-F Signal	<p>1. It is usually possible to rub the metal part of a screwdriver on the oscillator stator connection of the gang condenser and determine by the resultant noise from the loud speaker if the oscillator circuit is working or not. Very little noise is heard if it is not working. No body contact to the metal part of the screwdriver should be made.</p> <p>In most cases, depending on the circuit, a negative voltage can be read on the voltmeter across the oscillator grid leak resistor of from about two to fifteen on the broadcast band when the circuit is functioning. None or positive voltage indicates trouble.</p> <p>2. High or infinite resistance reading on ohmmeter across oscillator coil (primary and secondary if separate).</p>	<p>a. Dirty or open contacts on band switch.</p> <p>b. Shorted gang condenser. (Check with ohmmeter. Should be infinite resistance.)</p> <p>Open oscillator coil.</p>	<p>a. Clean contacts.</p> <p>b. Clear short in gang condenser.</p> <p>Change oscillator coil.</p>
Dial calibration off	<p>All calibration is result of oscillator circuit.</p> <p>Path of signal through amplifier is designated by > ></p>	<p>Dial mechanism mechanically out of line.</p>	<p>Realign per service notes.</p>

TROUBLE ANALYZING AND CORRECTIONS



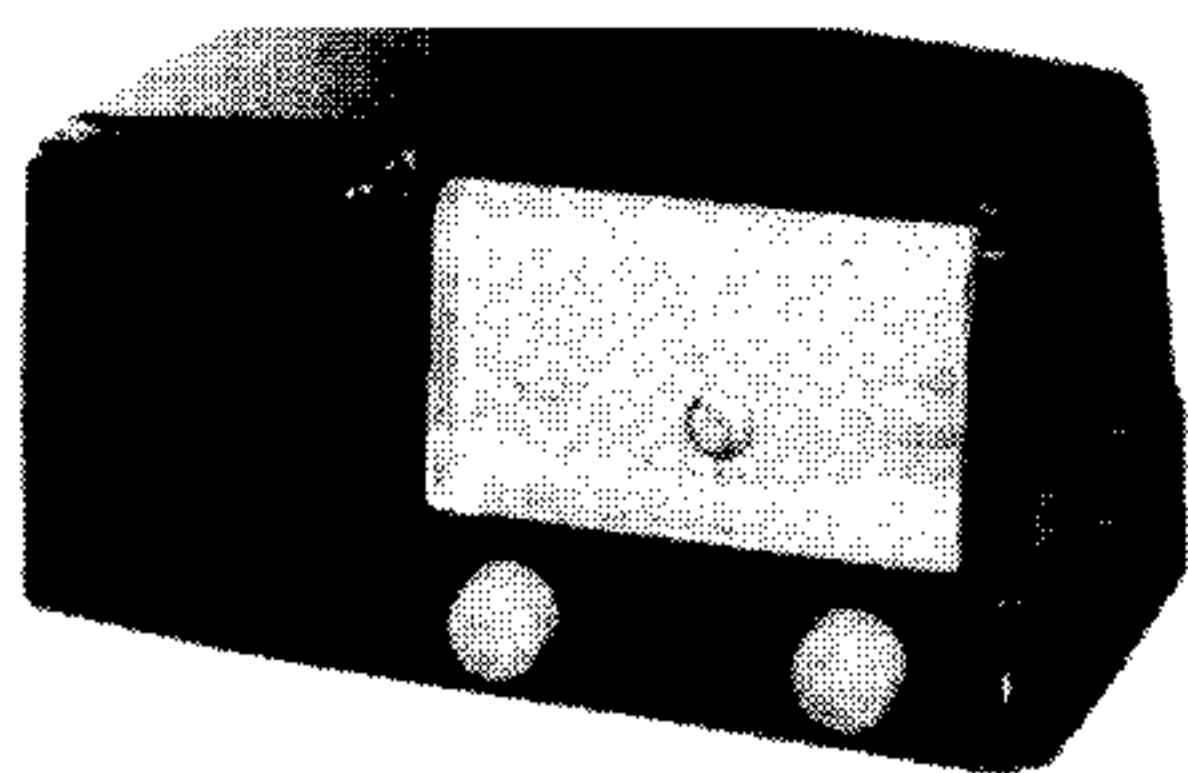
R. F. AMPLIFIER STAGE

Condition of this stage can be checked by feeding an r-f modulated signal from generator to antenna and ground posts.

Symptom Check	Probable Trouble	Remedy
Dead *1. No "B" plus voltage reading on voltmeter at screen grid of tube. 2. a. Signal from generator O.K. when fed between grid of tube and chassis, weak from antenna and ground. b. same as "a."	Shorted screen by-pass condenser. Open or dirty contacts in wave switch or wiring thereto. Open loop antenna circuit (check for correct reading on ohmmeter).	Change condenser. Clean or repair. Resolder open connection.

Path of signal through amplifier is designated by > >

Note: * Circuits in this stage may be totally inoperative and yet strong signals may be still reproduced due to leakage of signal into wiring, etc., to the converter tube.

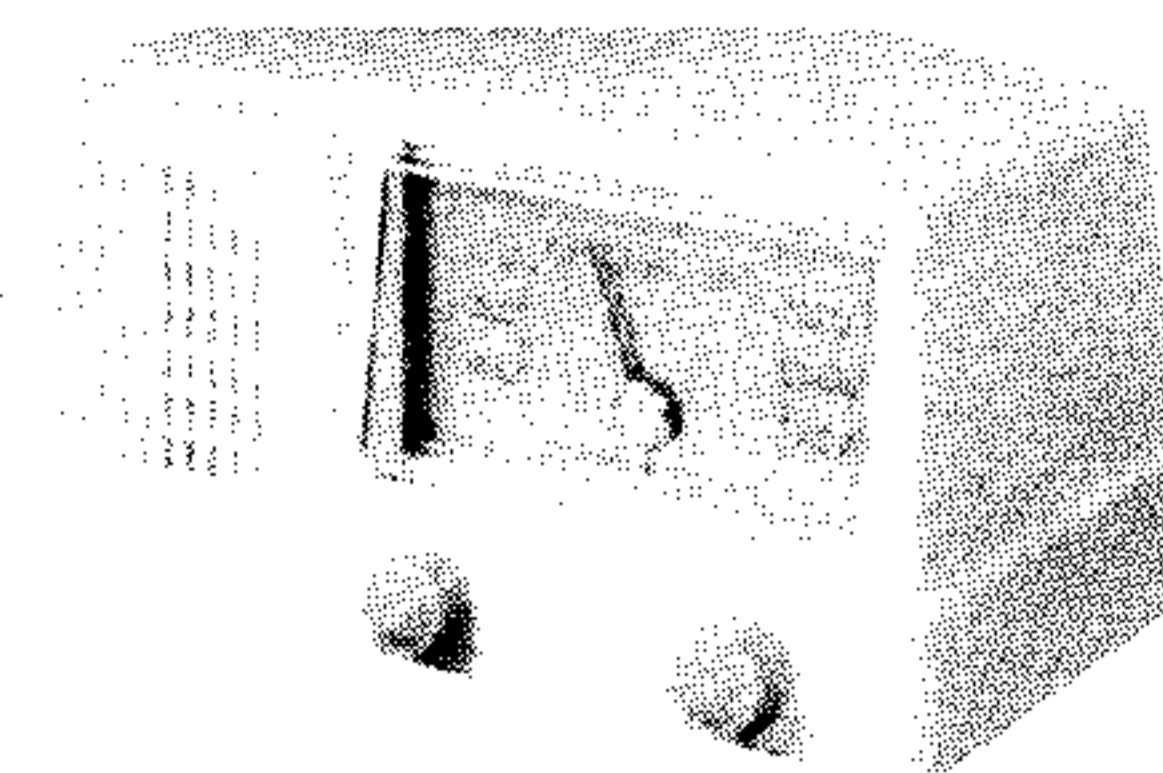


MODELS 400, 411

GENERAL ELECTRIC

RADIO SERVICE DATA FOR

MODELS 400, 401, AND 411



MODEL 401

SPECIFICATIONS

CABINET	Model	400	411	401
	Material	Brown	Maroon	Ivory
Height	6 $\frac{1}{8}$ in.			
Width	12 $\frac{1}{2}$ in.			
Depth	7 $\frac{1}{4}$ in.			
ELECTRICAL RATING	Voltage	105-125		
	Frequency	50-60 cycles or DC		
	Wattage	26 watts at 117 volts input		
OPERATING FREQUENCIES	Standard Broadcast	540-1600 kc		
	I-F Amplifier	455 kc		
POWER OUTPUT	Undistorted	1 watt		
	Maximum	1.75 watts		
LOUDSPEAKER	Type	Alnico V PM		
	Outside Cone Diameter	4 inches		
	Voice Coil Impedance at 400 Cycles	3.2 ohms		
TUBE COMPLEMENT	(V1) Oscillator-Converter	12SA7		
	(V2) I-F Amplifier	12BA6		
	(V3) Detector-Audio	12SQ7		
	(V4) Rectifier	35W4		
	(V5) Audio Power Amplifier	50C5		
	(I1) Pilot Lamp	G-E Mazda No. 47		

GENERAL INFORMATION

The Models 400, 401 and 411 are five-tube a-c or d-c super-heterodyne AM standard broadcast receivers equipped with an efficient built-in antenna loop and incorporating automatic volume control, a permanent magnet speaker, and beam power output.

ELECTRICAL CIRCUIT ALIGNMENT

EQUIPMENT REQUIRED

1. Test oscillator, tone amplitude-modulated.
2. A-C output meter, 1 $\frac{1}{2}$ volts full scale.
3. .05 mfd., paper capacitor.
4. Insulated screwdriver.
5. Coupling loop for test oscillator (see text).
6. Isolation power transformer.

ALIGNMENT PROCEDURE

The alignment steps are given in the table form of the Alignment Chart. Adjustment trimmers are shown in the illustration of Fig. 2.

1. The chassis is removed from the cabinet with the antenna loop and back attached and the speaker leads reconnected.
2. An isolation transformer should be used for the receiver power source when aligning or servicing, AC-DC receivers, to prevent short circuiting of equipment and shock hazard.
3. The output meter is connected across the terminals of the loudspeaker voice coil.
4. The receiver volume control should be turned to maximum and test oscillator signal output attenuated during alignment to develop not more than 1 $\frac{1}{4}$ volts output meter reading at the loudspeaker.
5. For i-f alignment, the high side of the signal generator output cable should be connected through a .05 mfd. paper ca-

pacitor to the points indicated in the Alignment Chart. The low side of the output cable is connected to the receiver chassis.

6. To align the oscillator and r-f trimmers, the signal generator output is inductively coupled to the radio loop, L1, by connecting a four-turn, six-inch diameter loop of bell wire across its output terminals and then locating the loop about one foot from the radio loop antenna. To prevent possible errors in comparative peak readings, the position of signal generator loop with respect to the radio loop antenna should not be changed during measurement.

ALIGNMENT CHART

Step	Connect Test Oscillator to:	Test Osc. Setting	Radio Dial Setting	Adjust Trimmers For Maximum
I-F ALIGNMENT				
1	V2, 12BA6 grid (Pin 1), in series with .05 mfd.	455 KC	C9 and C8 of second i-f transformer, T3
2	V1, 12SA7 grid (Pin 8), in series with .05 mfd.	455 KC	C6 and C5 of first i-f transformer, T2
3	V1, 12SA7 grid (Pin 8), in series with .05 mfd.	455 KC	Recheck adjustment of C9, C8, C6, C5, for maximum
R-F ALIGNMENT				
4	Inductively coupled to radio loop	1620 KC	Minimum capacity C2A, C2B	C3, oscillator trimmer
5	Inductively coupled to radio loop	1500 KC	1500 KC	C1, r-f trimmer

STAGE GAINS AND VOLTAGE CHECKS

Stage gain measurements by vacuum tube voltmeter or similar measuring device may be used to check circuit performance and isolate trouble. The gain values listed may have tolerances of 20 per cent. Readings are taken with low signal input so that AVC is not effective.

1. I-F GAIN

12SA7 Grid to 12BA6 Grid..... 50 @ 455 KC
12BA6 Grid to 12SQ7 Diode Plate..... 50 @ 455 KC

2. AUDIO GAIN

Input of 0.15 volts at 400 cycles across volume control (R4) with control set at maximum will develop approximately $\frac{1}{2}$ watt output across the speaker voice coil terminals.

3. OSCILLATOR GRID BIAS

D-C voltage developed across the oscillator grid leak (R1) averages 8.5 volts at 1000 kc.

4. TUBE SOCKET PIN VOLTAGES

Fig. 3 shows voltages from tube pins to B-. Voltage readings differing greatly from those specified may help localize defective components.

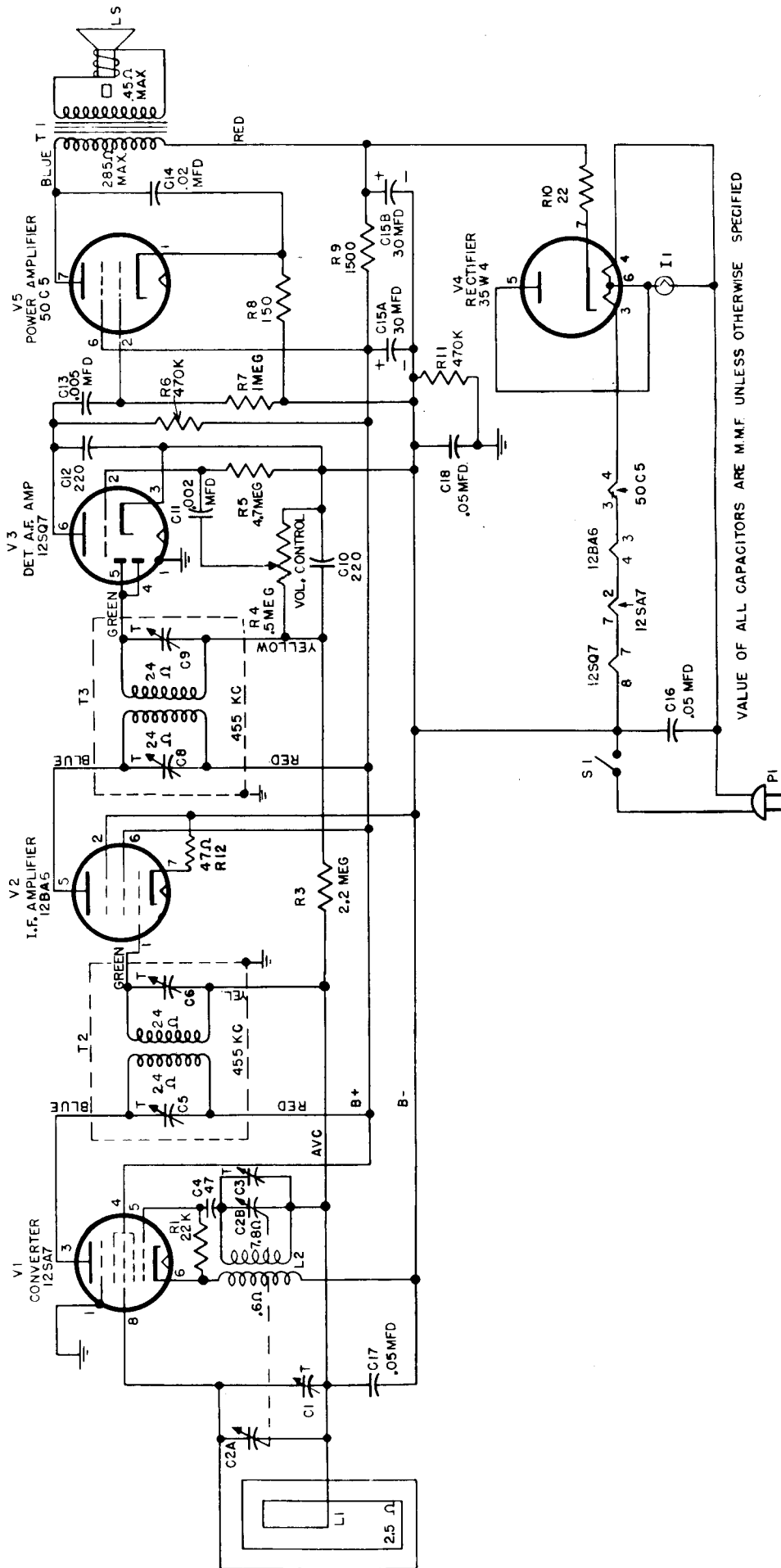


Fig. 1. Schematic diagram, Models 400, 401 and 411

VALUE OF ALL CAPACITORS ARE M.M.F. UNLESS OTHERWISE SPECIFIED

TERMS AND DEFINITIONS

A

"A" Power Supply. A power supply device providing heating current for the cathode or filament of the vacuum tube.

Alternating Current. A current the direction of which reverses at regularly recurring intervals.

Amplification Factor. A measure of the effectiveness of the grid voltage relative to that of the plate voltage in affecting the plate current.

Amplifier. A device for increasing the amplitude of electric current voltage or power.

A.M. Amplitude modulation.

Anode. An electrode to which an electron stream flows.

Antenna. A conductor or a system of conductors for radiating or receiving radio waves.

Atmospherics. Extraneous responses produced by atmospheric conditions.

Attenuation. The reduction in power of a wave, current or voltage.

Audio Frequency (a-f). A frequency corresponding to a normally audible sound wave. The upper limit ordinarily lies between 10,000 and 20,000 cycles.

Audio Frequency Transformer. A transformer for use with audio-frequency currents.

Autodyne Reception. A system of heterodyne reception through the use of a device which is both an oscillator and a detector.

Automatic Volume Control. A self-acting device which maintains the output constant within relatively narrow limits while the input voltage varies over a wide range.

Average Value. The average value of an alternating current or voltage taken over half a cycle. Is equal to $2/\pi$ times the maximum value or 0.636 times the maximum value. This is the value ordinarily indicated on a d-c measuring instrument.

B

"B" Power Supply. A power supply device providing voltage applied to plate circuits of a vacuum tube.

Baffle. A partition which may be used with an acoustic radiator to impede circulation between front and back.

Band-Pass Filter. A filter designed to pass currents of frequencies within a continuous band limited by an upper and a lower critical or cut-off frequency and substantially reduce the amplitude of currents of all frequencies outside that band.

Beam Tube. Usually a four-electrode vacuum tube which is enabled to exhibit pentode characteristics by reason of a virtual suppressor produced in the inter-electrode space by the directional control or focusing of the electron stream from the cathode.

Beat. A complete cycle of pulsations in the phenomenon of beating.

Beat Frequency. The number of beats per second. This frequency is equal to the difference between the frequencies of the combining waves.

Beating. A phenomenon in which two or more periodic quantities of different frequencies react to produce a resultant having pulsations of amplitude.

Break-in. The general term used to describe any type of radio system operation in which it is possible for a receiving station to interrupt the transmission at any time. In this way it is possible for the receiving operator to obtain "fills", and engage in conversation in a normal manner, without waiting for the completion of a long transmission.

Broadcasting. Radio transmission intended for general reception.

By-Pass Condenser. A condenser used to provide an alternating current path of comparatively low impedance around some circuit element.

C

"C" Power Supply. A power supply device providing voltage between cathode and grid in a vacuum tube circuit (grid bias).

Capacitive Coupling. The association of one circuit with another by means of capacity common or mutual to both.

Carbon Microphone. A microphone which depends for its operation upon the variation in resistance of carbon contacts.

Carrier. A term broadly used to designate carrier wave, carrier current or carrier voltage.

Carrier Frequency. The frequency of a carrier wave.

Carrier Suppression. That method of operation in which the carrier wave is not transmitted.

Carrier Wave. A wave which is modulated by a signal.

Cathode. The electrode from which the electron stream flows. Considered as indirectly heated.

Cathode Current. The total current passing to or from the cathode through the vacuous space.

Choke Coil. An inductor inserted in a circuit to offer relatively large impedance to alternating current.

Condenser Loud-Speaker. A loud-speaker in which the mechanical forces result from electrostatic reactions.

Condenser Microphone. A microphone which depends for its operation upon variations in capacitance.

Continuous Waves (CW). Continuous waves are waves in which successive cycles are identical under steady-state conditions.

Control Grid. Vacuum tubes, particularly high-vacuum tubes, frequently employ several grids interposed between cathode and anode. Perhaps the most important of these is the control grid, upon which is placed the input signal.

Conversion Conductance. The ratio of the intermediate frequency component of the plate or output current of a converter tube to the radio frequency component of the signal voltage applied to the control grid.

Conversion Gain. The ratio of the intermediate frequency voltage developed across the load to the radio frequency voltage applied to the control grid.

Converter. (Generally in superheterodyne receivers). A vacuum tube which performs simultaneously the functions of oscillation and mixing (first detection) in a radio receiver.

Counterpoise. A conducting network having low radio-frequency and direct current resistance, which is insulated from, supported above, and spaced relatively near to the ground immediately under, an antenna. No radio-frequency ground connection is used with equipment employing a counterpoise, the counterpoise connection being used in its place. Counterpoises are used especially with transmitters which must be installed at locations where adequate ground connections cannot be made due to the high resistance of the soil at the antenna site.

Coupling. The association of two circuits in such a way that energy may be transferred from one to the other.

Cross Modulation. A type of intermodulation due to modulation of the carrier of the desired signal in a radio apparatus by an undesired signal.

Crystal Oscillator. A vacuum tube in whose grid circuit a piezo-electric quartz crystal is connected for the purpose of stabilizing the frequency of oscillation.

Current Amplification. The ratio of the alternating current produced in the output circuit of an amplifier to the alternating current supplied to the input circuit for specific circuit conditions.

Cycle. One complete set of the recurrent values of a periodic phenomenon.

D

Damped Waves. Waves of which the amplitude of successive cycles, at the source, progressively diminishes.

Decibel. The unit of power-level difference, measured by $10 \log_{10} W_2/W_1$, where W_2 is a power controlled by W_1 . Used as a measure of response in all types of electrical communication circuits.

Detection. Any process whereby signal information is extracted from a modulated wave.

Detector. The device which is to extract signal information from a modulated wave.

Diaphragm. A vibrating surface which produces sound vibrations.

Diode. A type of thermionic tube containing two electrodes which passes current wholly or predominantly in one direction.

Direct Coupling. The association of two circuits through a common conductor.

Direct Current. A unidirectional current. As ordinarily used, the term designates a practically non-pulsating current.

Distortion. A change in wave form occurring in a transducer or transmission medium when the output wave form is not a faithful reproduction of the input wave form.

Doubler. A vacuum tube whose plate circuit is tuned to twice the radio frequency of its grid circuit. Doublers, therefore, serve to double the radio frequency, at some sacrifice in power amplification.

Dynamic Characteristic. The dynamic characteristic of a vacuum tube represents the instantaneous and relative changes in the tube parameters under actual load conditions with alternating input and output voltages.

Dynamic Plate Resistance (of a vacuum tube). The ratio of its amplification factor to its mutual conductance. It is a measure of the change in instantaneous plate voltage resulting from a given change in instantaneous plate current under essentially constant grid-voltage conditions.

E

Effective Value. The root mean square value of an alternating quantity, is equal to 0.707 times the maximum value, and is the value indicated by thermocouple-type meters.

Electron Coupling. Coupling between two circuits due to an electron stream.

Electron Emission. The liberation of electrons from an electrode into the surrounding space.

Electron Tube. An evacuated tube, the characteristics of which are due essentially to electron emission.

F

Facsimile Transmission. The electrical transmission of a copy or reproduction of a picture, drawing, or document. (This is also called picture transmission).

Fading. The variation of the signal intensity received at a given location from a radio transmitting station as a result of changes occurring in the transmission path. (See Distortion).

Fidelity. The degree to which a system, or a portion of a system — such as in a transmitter or receiver — accurately reproduces at its output the signal which is impressed upon it.

Filament. A cathode in which the heat is supplied by current passing through the cathode.

Filter. A selective circuit network, designed to pass currents within a continuous band or bands of frequencies or direct current, and substantially reduce the amplitude of currents of undesired frequencies.

Frequency. The number of cycles per second.

FM. Frequency modulation.

Fundamental Frequency. The lowest component frequency of a periodic wave or quantity.

G

Gas Phototube. A type of phototube in which a quantity of gas has been introduced, usually for the purpose of increasing its sensitivity.

Grid. An electrode having openings through which electrons or ions may pass.

Grid Bias (of a vacuum tube). The magnitude of the negative d-c voltage applied between the control grid and the cathode. Its purpose may be to cause the tube to operate over those portions of its characteristic most suitable for the type of operation desired, or to limit the magnitude of the plate current to safe values.

Grid Blocking. The stoppage of plate current flow in a vacuum tube due to an excessive accumulation of electrons on the grid which do not let off quickly enough.

Grid Condenser. A series condenser in the grid or control circuit of a vacuum tube.

Grid Leak. A resistor in a grid circuit, through which the grid current flows, to effect or determine a grid bias.

Grid-Plate Transconductance. The name for the plate-current to grid-voltage transconductance. (This has also been called mutual conductance).

Ground System (of an antenna). That portion of the antenna system below the antenna loading devices or generating apparatus most closely associated with the ground and including the ground itself.

Ground Wire. A conductive connection to the earth.

H

Half-Wave Rectifier. A rectifier which changes alternating current into pulsating current, utilizing only one-half of each cycle.

Harmonic. A component of a periodic quantity having a frequency which is an integral multiple of the fundamental frequency. For example, a component the frequency of which is twice the fundamental frequency is called the second harmonic.

Heater. An electric heating element for supplying heat to an indirectly heated cathode.

Heterodyne Reception. The process of receiving radio waves by combining in a detector a received voltage with a locally generated alternating voltage. The frequency of the locally generated voltage is commonly different from that of the received voltage. (Heterodyne reception is sometimes called beat reception).

Homodyne Reception. A system of reception by the aid of a locally generated voltage of carrier frequency. (Homodyne reception is sometimes called zero-beat reception).

Hot-Wire Ammeter, Expansion Type. An ammeter dependent for its indications on a change in dimensions of an element which is heated by the current to be measured.

I

Indirectly Heated Cathode. A cathode of a thermionic tube, in which heat is supplied from a source other than the cathode itself.

Induction Loud-Speaker. A moving-coil loud-speaker in which the current which reacts with the polarizing field is induced in the moving member.

Inductive Coupling. The association of one circuit with another by means of inductance common or mutual to both.

Interelectrode Capacitance. The direct capacitance between two electrodes.

Interference. Disturbance of reception due to strays, undesired signals, or other causes; also that which produces the disturbance.

Intermediate Frequency (i-f) (in superheterodyne reception). A frequency between that of the carrier and the signal, which results from the combination of the carrier frequency and the locally generated frequency.

Intermodulation. The production, in a nonlinear circuit element, of frequencies corresponding to the sums and differences of the fundamentals and harmonics of two or more frequencies which are transmitted to that element.

Interrupted Continuous Waves (ICW). Interrupted continuous waves are waves obtained by interruption at audio frequency in a substantially periodic manner of otherwise continuous waves.

K

Kilocycle. A thousand cycles per second, when used as a unit of frequency.

L

Lead-in. That portion of an antenna system which completes the electrical connection between the elevated outdoor portion and the instruments or disconnecting switches inside the building.

Linear Detection. That form of detection in which the audio output voltage under consideration is substantially proportional to the modulation envelope throughout the useful range of the detecting device.

Loading Coil. An inductor inserted in a circuit to increase its inductance but not to provide coupling with any other circuit.

Load Impedance (of a vacuum tube). The alternating-current effective resistance into which the vacuum tube works. For linear operation it is numerically equal to the reciprocal of the slope of the load line as drawn on the plate characteristic.

Loud-Speaker. A telephone receiver designed to radiate acoustic power into a room or open air.

M

Magnetic Loud-Speaker. One in which the mechanical forces result from magnetic reactions.

Magnetic Microphone. A microphone whose electrical output results from the motion of a coil or conductor in a magnetic field.

Master Oscillator. An oscillator of comparatively low power so arranged as to establish the carrier frequency of the output of an amplifier.

Maximum Peak Inverse Voltage. The highest peak voltage that a rectifier can safely withstand in the opposite direction to that in which it is designed to pass current. In single phase, full-wave circuits with sinusoidal input voltage wave form, the peak inverse voltage is approximately 1.4 times the r-m-s value of the voltage when no condenser is used across the output. In half-wave circuits with sinusoidal input and a condenser input type of filter, the peak inverse voltage may reach 2.8 times the r-m-s value of the applied plate voltage.

Maximum Peak Plate Current. The highest peak current that a rectifier can safely stand in the direction in which the tube is designed to pass current. This value is largely determined, in any given circuit, by the filter system employed.

Megacycle. A million cycles per second, when used as a unit of frequency.

Mercury-Vapor Rectifier. A two-electrode, vacuum-tube rectifier which contains a small amount of mercury. During operation, the mercury is vaporized. A characteristic of mercury-vapor rectifiers is the low voltage drop in the tube.

Microphone. An electroacoustic transducer actuated by power in an acoustic system and delivering power to an electric system, the wave form in the electric system corresponding to the wave form in the acoustic system. This is also called a telephone transmitter.

Types of microphones in general use include single-button carbon, double-button or push-pull carbon, ribbon, dynamic, and crystal. Each type of microphone has its individual operating advantages, as for example in connection with fidelity, audio voltage output, size, weight, and cost. The single-button carbon microphone is the cheapest, smallest, and lightest, and is capable of large audio outputs; its fidelity, however, is inferior to that of many other types.

Mixer Tube (generally in superheterodyne receivers). A tube in which a locally generated frequency is combined with the carrier-signal frequency to obtain a desired beat frequency.

Modulated Wave. A wave of which the amplitude, frequency, or phase is varied in accordance with a signal.

Modulation. The process by which the amplitude, frequency, or phase of a wave is varied in accordance with a signal; or the result of that process.

Modulator. A device which performs the process of modulation.

Monochromatic Sensitivity. The response of a phototube to light of a given color, or narrow frequency range.

Moving-Armature Speaker. A magnetic speaker whose operation involves the vibration of a portion of the ferromagnetic circuit. (This is sometimes called an electromagnet or a magnetic speaker).

Moving-Coil Loud-Speaker. A magnetic loud-speaker in which the mechanical forces are developed by the interaction of currents in a conductor and the polarizing field in which it is located. This is sometimes called an electrodynamic or a dynamic loud-speaker.

MU-Factor. A measure of the relative effect of the voltages on two electrodes upon the current in the circuit of any specified electrode. It is the ratio of the change in one electrode voltage to a change in the other electrode voltage, under the condition that a specified current remains unchanged.

Mutual Conductance. One of the more important operating characteristics of a vacuum tube. It is a measure of the effectiveness of the control-grid signal voltage in influencing the plate current at essentially constant plate voltage. This quantity is also known as "transconductance."

N

Neutralization. That process whereby in a triode amplifier stage a portion of the out-of-phase output radio-frequency voltage is fed back into the grid circuit for the purpose of balancing out or neutralizing the radio-frequency energy feed back from the plate to the grid circuit through the interelectrode capacities of the tube. The purpose of neutralizing an amplifier stage is to preclude its self-oscillation, and to increase its reaction frequency stability.

Noise Suppression. That operational characteristic of a radio receiver by which it is enabled materially to reduce the noise output of the receiver during periods when no carrier is being received.

O

Oscillator. A nonrotating device for producing alternating current, the output frequency of which is determined by the characteristics of the device.

Oscillatory Circuit. A circuit containing inductance and capacitance, such that a voltage impulse will produce a current which periodically reverses.

P

Parasitics. Unwanted, frequently spasmodic, oscillations.

Peak Value (of an alternating-current wave). Its amplitude or maximum value, which may be measured by means of a peak vacuum-tube voltmeter.

Pentode. A type of thermionic tube containing a plate, a cathode, and three additional electrodes. (Ordinarily the three additional electrodes are of the nature of grids).

Percentage Modulation. The ratio of half the difference between the maximum and minimum amplitudes of a modulated wave to the average amplitude, expressed in per cent.

Phonograph Pickup. An electromechanical transducer actuated by a phonograph record and delivering power to an electrical system, the wave form in the electrical system corresponding to the wave form in the phonograph record.

Phototube. A vacuum tube in which electron emission is produced by the illumination of an electrode. (This has also been called photo-electric tube).

Plate. A common name for the principal anode in a vacuum tube.

Power Amplification (of an amplifier). The ratio of the alternating-current power produced in the output circuit to the alternating-current power supplied to the input circuit.

Power Detection. That form of detection in which the power output of the detecting device is used to supply a substantial amount of power directly to a device such as a loud-speaker or recorder.

Power Output (P.O.). The a-c power produced in an external non-inductive resistor of specified value connected in the plate circuit of the amplifier. For any particular case the maximum power output will be determined by an arbitrary criterion of permissible total harmonic distortion.

Pulsating Current. A periodic current, that is, current passing through successive cycles, the algebraic average value of which is not zero. A pulsating current is equivalent to the sum of an alternating and a direct current.

Push-Pull. Two vacuum tubes are said to be operating in a push-pull connection when their grid circuits are fed respectively from driving points 180 degrees out of phase, the plate-circuit load similarly exhibiting 180 degrees phase displacement plate to plate. The common cathode connection is tapped onto the midpoints of the input and output circuits. The total driving and output voltages are, therefore, twice those of the comparable parallel connection, but the currents are half for the same power output.

R

Radio Channel. A band of frequencies or wavelengths of a width sufficient to permit of its use for radio communication. The width of a channel depends upon the type of transmission.

Radio Compass. A direction finder used for navigational purposes.

Radio Frequency (r-f). A frequency higher than those corresponding to normally audible sound waves. (See audio frequency).

Radio-Frequency Transformer. One used with radio-frequency currents.

Radio Receiver. A device for converting radio waves into perceptible signals.

Radio Transmission. The transmission of signals by means of radiated electro-magnetic waves originating in a constricted circuit.

Radio Transmitter. A device for producing radio-frequency power, with means for producing a signal.

Rectifier. A device having an asymmetrical conduction characteristic which is used for the conversion of an alternating current into a pulsating current. Such devices include vacuum-tube rectifiers, gas rectifiers, oxide rectifiers, electrolytic rectifiers, etc.

Reflex Circuit Arrangement. A circuit arrangement in which the signal is amplified, both before and after detection, in the same amplifier tube or tubes.

Regeneration. The process by which a part of the output power of an amplifying device reacts upon the input circuit in such a manner as to reinforce the initial power, thereby increasing the amplification. (Sometimes called "feed-back").

Resistance Coupling. The association of one circuit with another by means of resistance common to both.

Resonance. A condition which exists in a circuit containing inductance and capacitance when its equivalent reactance is zero. When the inductance and capacitance are connected in series, the current in the circuit is a maximum. When the inductance and capacitance are connected in parallel, the external current is approximately a minimum.

Resonantly tuned circuits exhibit low series reactance and high shunt impedance at the resonant frequency. Antenna circuits are tuned to series resonance to enable them to be driven by low excitation

voltages; tank circuits are tuned to shunt resonance in order that they may present a load to the driving tube of optimum impedance at the output frequency. The current and voltage driving resonantly tuned tank circuits are approximately in phase (unity power-factor), since the equivalent reactance is essentially zero. The current and voltage associated with the internal circulating energy in resonantly tuned tank circuits are approximately in quadrature (zero power-factor), since the equivalent tank series resistance must be small relatively to either the inductive or the capacitive reactance.

Resonance Frequency (of a reactive circuit). The frequency at which the supply current and supply voltage of the circuit are in phase.

Ripple Voltage. The alternating component of unidirectional voltage from a rectifier or generator used as a source of d-c power.

S

Screen Grid (of a vacuum tube). Primarily an electrostatic shield, maintained at a fixed positive potential, interposed between the control grid and the anode for the purpose of minimizing reactions from the plate circuit back through the interelectrode tube capacities to the input or control-grid circuit.

Secondary Emission. Electron emission under the influence of electron or ion bombardment.

Selectivity. The degree to which a radio receiver is capable of differentiating between signals of different carrier frequencies. It is commonly expressed in terms of the acceptance band width in kc for signals 6, 20, 40, and 60 db down from resonance.

Sensitivity. The degree to which a radio receiver responds to signals of the frequency to which it is tuned. It is commonly expressed in terms of the field strength in microvolts per meter requisite to produce normal output using a standard antenna.

Sensitivity of a Phototube. The electric current response of a photo-tube, with no impedance in its external circuit, to a specified amount and kind of light. It is usually expressed in terms of the current for a given radiant flux, or for a given luminous flux. In general the sensitivity depends upon the tube voltage, flux intensity, and spectral distribution of the flux.

Side Bands. Those bands of radio frequencies immediately adjacent to the carrier frequency, and separated therefrom by exactly the frequencies of the modulation responsible for them. There is an upper side band associated with a lower side band for each band of modulating frequencies. The higher the maximum modulating frequency, therefore, the wider the requisite radio-frequency channel for the transmission of this intelligence.

Signal. The intelligence, message, or effect conveyed in communication.

Single-Side-Band Transmission. That method of operation in which one side band is transmitted, and the other side band is suppressed. The carrier wave can be either transmitted or suppressed.

Space Charge. Space charge is said to exist in a vacuum tube when the volume density in the electron stream from the cathode to anode reaches such a value as to result in an appreciable voltage gradient in the interelectrode space. In high-vacuum tubes, space charge is the ultimate limitation on the magnitude of plate current that it is possible to draw through the tube. In gas-filled tubes, space charge is almost entirely eliminated by the neutralizing action of the gas positive ions. This enables much higher currents to be drawn through gas-filled tubes with much lower voltage gradients within the interelectrode space.

Static. Strays produced by atmospheric conditions.

Static Characteristic. The static characteristic of a vacuum tube represents the relations of the tube parameters such as grid voltage, grid current, plate voltage, plate current, etc., under steady state or d-c conditions, and therefore no load.

Static Sensitivity of a Phototube. The direct-current response of a photo-tube to a light flux of specified value.

Stopping Condenser. A condenser used to introduce a comparatively high impedance in some branch of a circuit for the purpose of limiting the flow of low-frequency alternating current or direct current without materially affecting the flow of high-frequency alternating current.

Strays. Electromagnetic disturbances in radio reception other than those produced by radio-transmitting systems.

Superheterodyne Reception. Superheterodyne reception is a method of reception in which the received voltage is combined with the voltage from a local oscillator and converted into voltage of an intermediate frequency which is usually amplified and then detected to reproduce the original signal wave. (This is sometimes called double detection or supersonic reception).

Suppressor Grid. The suppressor grid of a vacuum tube can be used for several purposes. It is interposed between the cathode and anode immediately adjacent to the anode. It can be connected, either internally or externally, to the cathode, and when so connected is effective in limiting secondary emission from the anode. The suppressor grid can also be externally connected to a source of audio-frequency modulating voltage for the suppressor-grid modulation of the tube when used as a radio-frequency amplifier. Suppressor-grid connections are also used in many receiver circuits supplementing automatic volume control, noise suppression, etc.

Swinging. The momentary variation in frequency of a received wave.

T

Tank Circuit. A circuit comprising an inductance in shunt with a capacitance, one usually being variable. The combination is tuned to the stage output frequency.

Telephone Receiver. An electroacoustic transducer actuated by power from an electric system and sup-

plying power to an acoustic system, the wave form in the acoustic system corresponding to the wave form in the electric system.

Television. The electric transmission of a succession of images and their reception in such a way as to give a substantially continuous reproduction of the object or scene before the eye of a distant observer.

Tetrode. A type of thermionic tube containing a plate, a cathode, and two additional electrodes. (Ordinarily, the two additional electrodes are of the nature of grids).

Thermionic. Relating to electron emission under the influence of heat.

Thermionic Emission. Electron or ion emission under the influence of heat.

Thermionic Tube. An electron tube in which the electron emission is produced by the heating of an electrode.

Thermocouple Ammeter. An ammeter dependent for its indications on the change in thermoelectromotive force set up in a thermoelectric couple which is heated by the current to be measured.

Total Emission. The value of the current carried by electrons emitted from a cathode under the influence of a voltage such as will draw away all the electrons emitted.

Transceiver. A combined radio transmitting and receiving equipment, usually entirely within one housing, for use in portable and mobile applications. The distinguishing characteristic of this type of equipment is the common use for both transmitting and receiving of all or part of the vacuum-tube complement, and of other circuit components such as the audio-frequency amplifier.

Transconductance. (See Mutual conductance).

Transducer. A device actuated by power from one system and supplying power to another system. These systems may be electric, mechanical, or acoustic.

Triode. A type of thermionic tube containing an anode, a cathode, and a third electrode, in which the current flowing between the anode and the cathode may be controlled by the voltage between the third electrode and the cathode.

Tuned Transformer. A transformer whose associated circuit elements are adjusted as a whole to be resonant at the frequency of the alternating current supplied to the primary, thereby causing the secondary voltage to build up to higher values than would otherwise be obtained.

Tuning. The adjustment of a circuit or system to obtain optimum performance in relation to a frequency; commonly, the adjustment of a circuit or circuits to resonance.

V

Vacuum Phototube. A type of phototube which is evacuated to such a degree that the residual gas plays a negligible part in its operation.

Vacuum Tube. A device consisting of a number of electrodes contained within an evacuated enclosure.

Vacuum-Tube Transmitter. A radio transmitter in which vacuum tubes are utilized to convert the applied electric power into radio-frequency power.

Vacuum-Tube Voltmeter. A device utilizing the characteristics of a vacuum tube for measuring alternating voltages.

Voltage Amplification (or Gain). The ratio of the alternating voltage produced at the output terminals of an amplifier to the alternating voltage impressed at the input terminals.

Voltage Divider. A resistor provided with fixed or movable contacts and with two fixed terminal contacts; current is passed between the terminal contacts, and a desired voltage is obtained across a portion of the resistor. (The term potentiometer is often erroneously used for this device).

W

- Wave.** a. A propagated disturbance, usually periodic, as an electric wave or sound wave.
b. A single cycle of such a disturbance, or
c. A periodic variation as represented by a graph.

Wavelength. The distance traveled in one period or cycle by a periodic disturbance. The wavelength in meters, λ , and the frequency in megacycles, f , of radio waves are related in accordance with the expression, $\lambda f = 300$.

Wavetrap. A series or shunt connected resonant circuit, connected in a circuit to attenuate an undesired wave. (Usually connected in antenna circuits of receivers).

Multiples and Sub-Multiples

Ampere	=	1,000,000	microamperes
Ampere	=	1,000	milliamperes
Cycle	=	0.000,001	megacycle
Cycle	=	0.001	kilocycle
Farad	=	1,000,000,000,000	micro-microfarads
Farad	=	1,000,000	microfarads
Farad	=	1,000	millifarads
Henry	=	1,000,000	microhenrys
Henry	=	1,000	millihenrys
Kilocycle	=	1,000	cycles
Kilovolt	=	1,000	volts
Kilowatt	=	1,000	watts
Megacycle	=	1,000,000	cycles
Megohm	=	1,000,000	ohms
Mho	=	1,000,000	micromhos
Mho	=	1,000	millimhos
Microampere	=	0.000,001	ampere
Microfarad	=	0.000,001	farad
Microhenry	=	0.000,001	henry
Micromho	=	0.000,001	mho
Micro-ohm	=	0.000,001	ohm
Microvolt	=	0.000,001	volt
Microwatt	=	0.000,001	watt
Micromicrofarad	=	0.000,000,000,001	farad
Milliampere	=	0.001	ampere
Millihenry	=	0.001	henry
Millimho	=	0.001	mho
Milliohm	=	0.001	ohm
Millivolt	=	0.001	volt
Milliwatt	=	0.001	watt
Volt	=	1,000,000	microvolts
Volt	=	1,000	millivolts
Watt	=	1,000,000	microwatts
Watt	=	1,000	milliwatts
Watt	=	0.001	kilowatt

Metric Prefixes

μ	$\frac{1}{1,000,000}$	One-millionth	micro-
m	$\frac{1}{1,000}$	One-thousandth	milli-
c	$\frac{1}{100}$	One-hundredth	centi-
d	$\frac{1}{10}$	One-tenth	deci-
	1	One	uni-
dk	10	Ten	deka-
h	100	One hundred	hekto-
k	1,000	One thousand	kilo-
	10,000	Ten thousand	myria-
M	1,000,000	One million	mega-

Symbols for Electrical Quantities

Admittance	Y, y
Angular velocity ($2\pi f$)	ω
Capacitance	C
Conductance	G, g
Conductivity	ν
Current	I, i
Difference of potential	E, e
Dielectric constant	K or ϵ
Energy	W
Frequency	f
Impedance	Z, z
Inductance	L
Magnetic intensity	H
Magnetic flux	Φ
Magnetic flux density	B
Magnetomotive force	F
Mutual inductance	M
Number of conductors or turns	N
Permeability	μ
Phase displacement	θ or ϕ
Power	P, p
Quantity of electricity	Q, q
Reactance	X, x
Reactance, Capacitive	X_c
Reactance, Inductive	X_L
Resistance	R, r
Resistivity	ρ
Susceptance	b
Speed of rotation	n
Voltage	E, e
Work	W

Greek Letter	Greek Name	English Equivalent
A α	Alpha	a
B β	Beta	b
Γ γ	Gamma	g
Δ δ	Delta	d
E ϵ	Epsilon	e
Z ζ	Zeta	z
H η	Eta	\bar{e}
Θ θ	Theta	th
I ι	Iota	i
K κ	Kappa	k
Λ λ	Lambda	l
M μ	Mu	m
N ν	Nu	n
Ξ ξ	Xi	x
O \omicron	Omicron	o
Π π	Pi	p
P ρ	Rho	r
Σ σ	Sigma	s
T τ	Tau	t
Υ υ	Upsilon	u
Φ ϕ	Phi	ph
X χ	Chi	ch
Ψ ψ	Psi	ps
Ω ω	Omega	\bar{o}

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